Title: Progress and Puzzles in String Gas Cosmology

Date: Mar 07, 2008 02:00 PM

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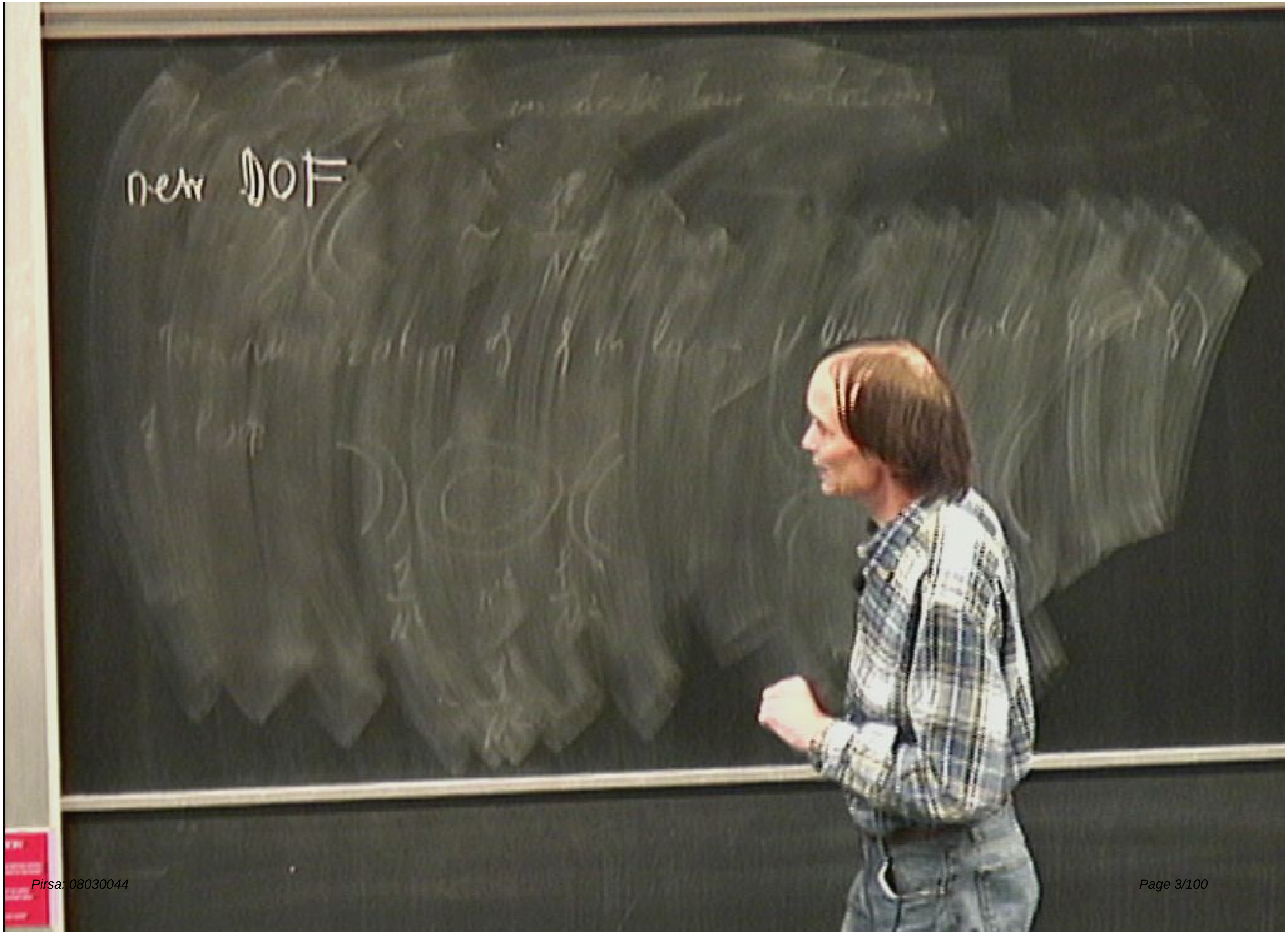
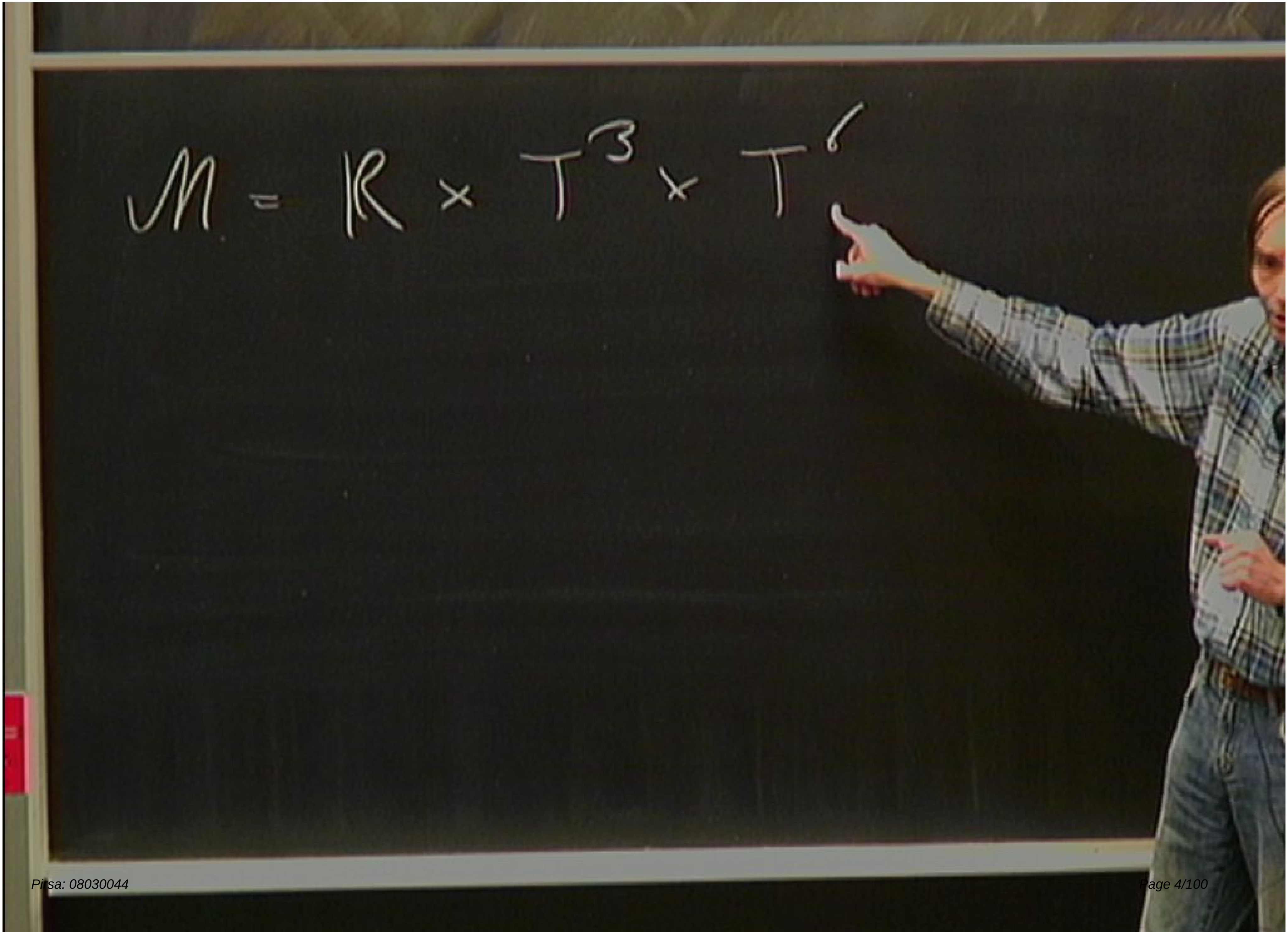
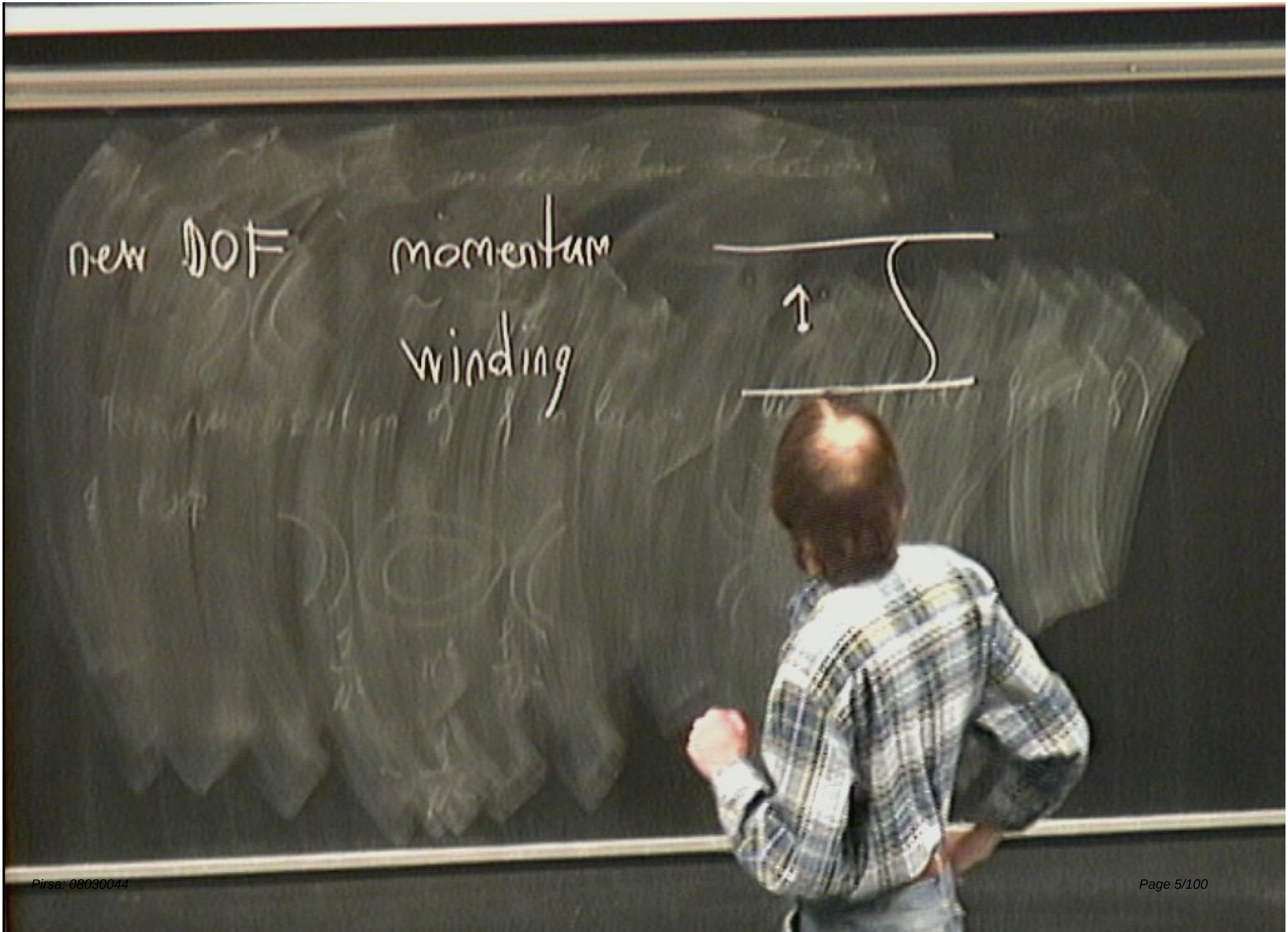
Abstract:

Outline

1. String Gas Cosmology (SGC) — R.B. & C. Vafa 89
2. SGC & Structure Formation — A. Nayeri, R.B. & C. Vafa 05
3. Moduli Stabilization in SGC — S. Patil & R.B. 05
   E. Cheung et.al 05
4. Background for SGC — R. Danos, A. Frey & R.B 08
5. SGC & Flatness Problem — R.B., A. Frey & S. Kanno 07
   N. Lashkari


new DOF


$\mathcal{M} = \mathbb{R} \times T^3 \times T^6$


new DOF
momentum
winding

new DOF momentum

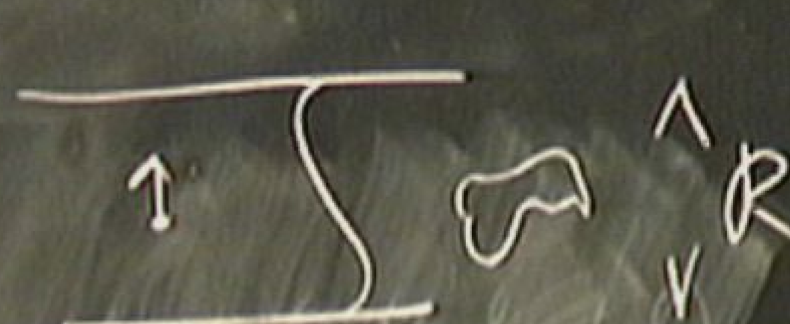
winding

oscillators

new DOF momentum

winding

oscillators



$E = \frac{n}{R}$

new DOF momentum

winding

oscillators

$E = mR$

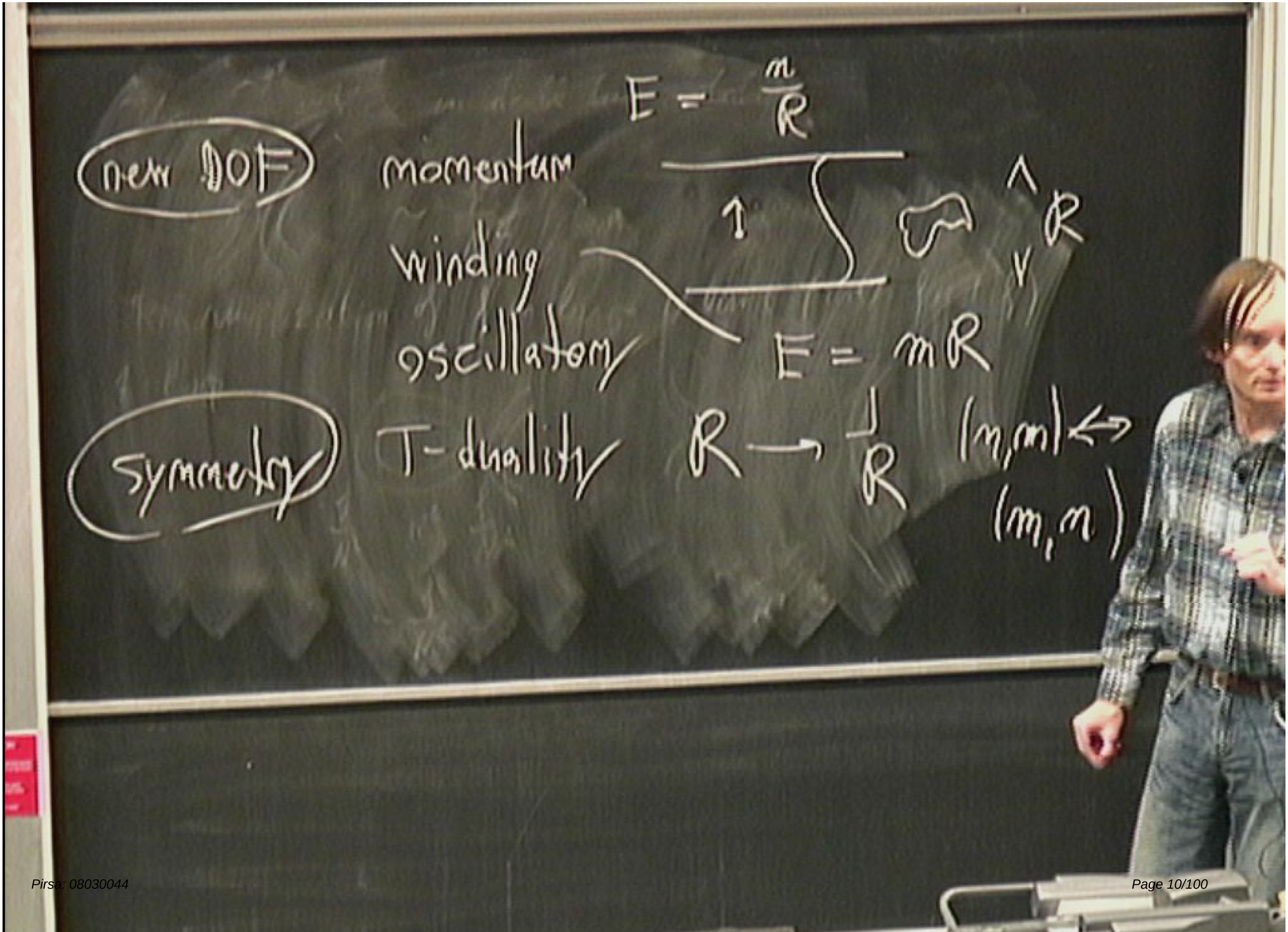
R

new DOF — momentum — $E = \frac{n}{R}$

winding — R

oscillators — $E = mR$

symmetry — T-duality — $R \to \frac{1}{R}$ — $(n,m) \leftrightarrow (m,n)$



new DOF
momentum
$E = \frac{n}{R}$
winding
$E = mR$
oscillators
symmetry
T-duality
$R \to \frac{1}{R}$
$(n,m) \leftrightarrow (m,n)$

$E = \frac{n}{R}$

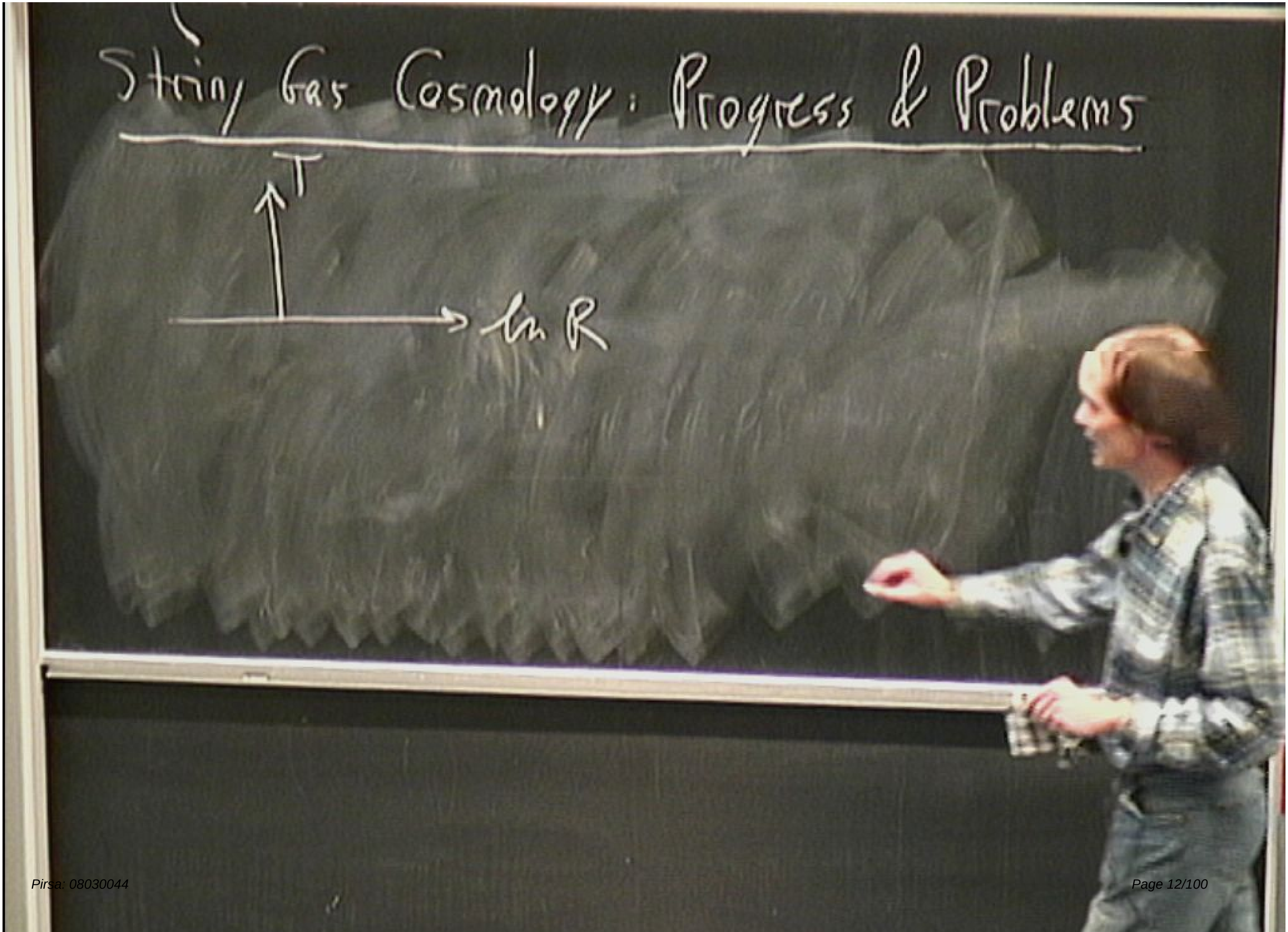
new DOF momentum

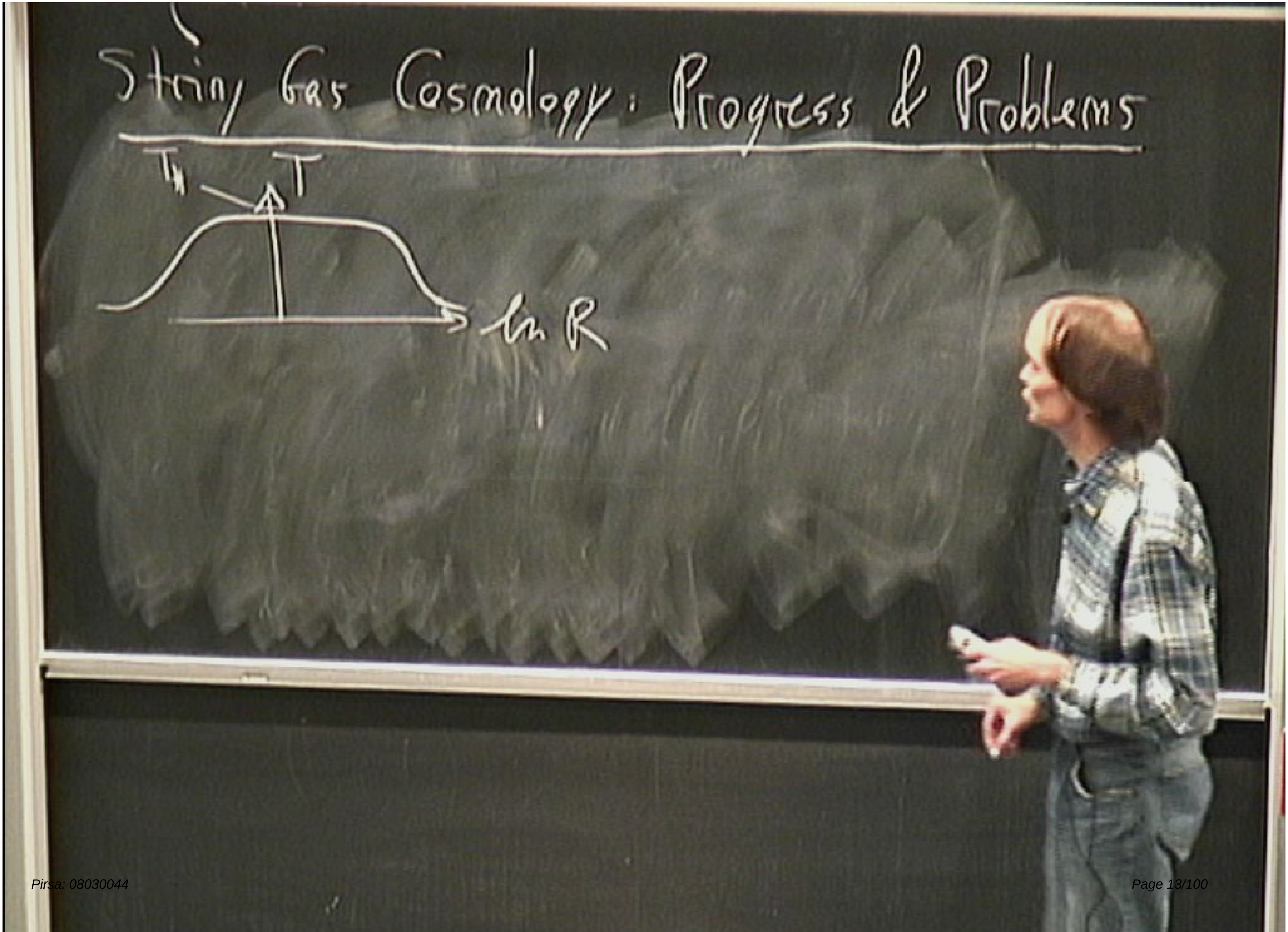
winding

oscillators $E = mR$

symmetry T-duality $R \to \frac{1}{R}$ $(n,m) \leftrightarrow (m,n)$

$T \leq T_H$


String Gas Cosmology: Progress & Problems
T
ln R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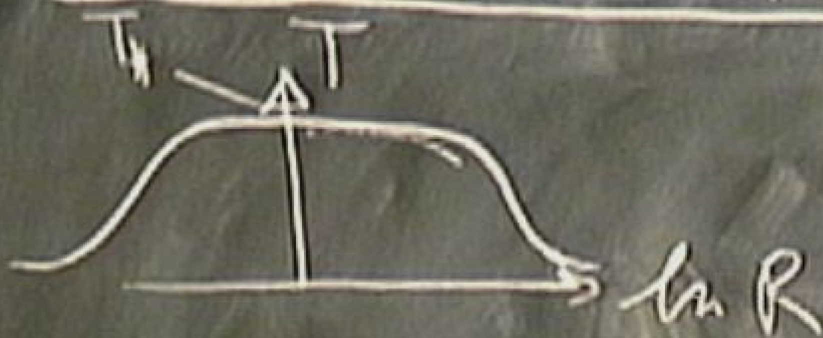
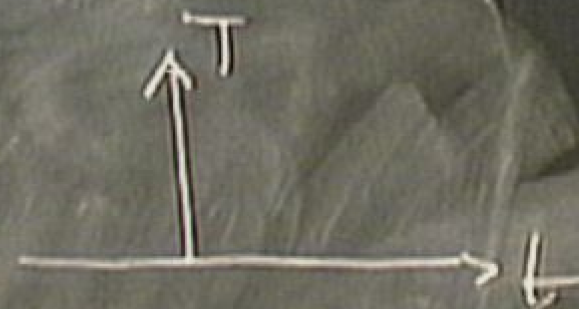
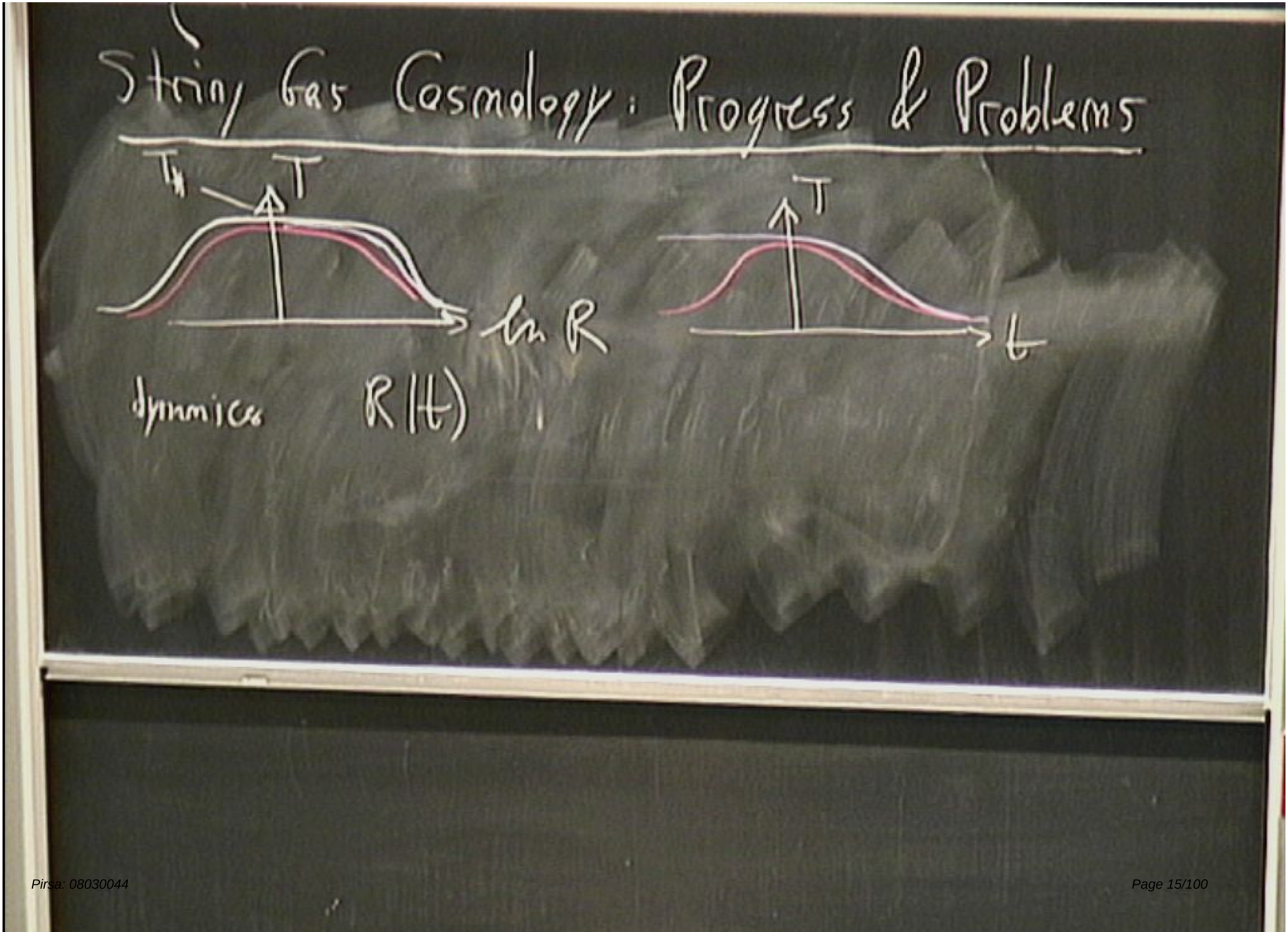
T_H
T
ln R

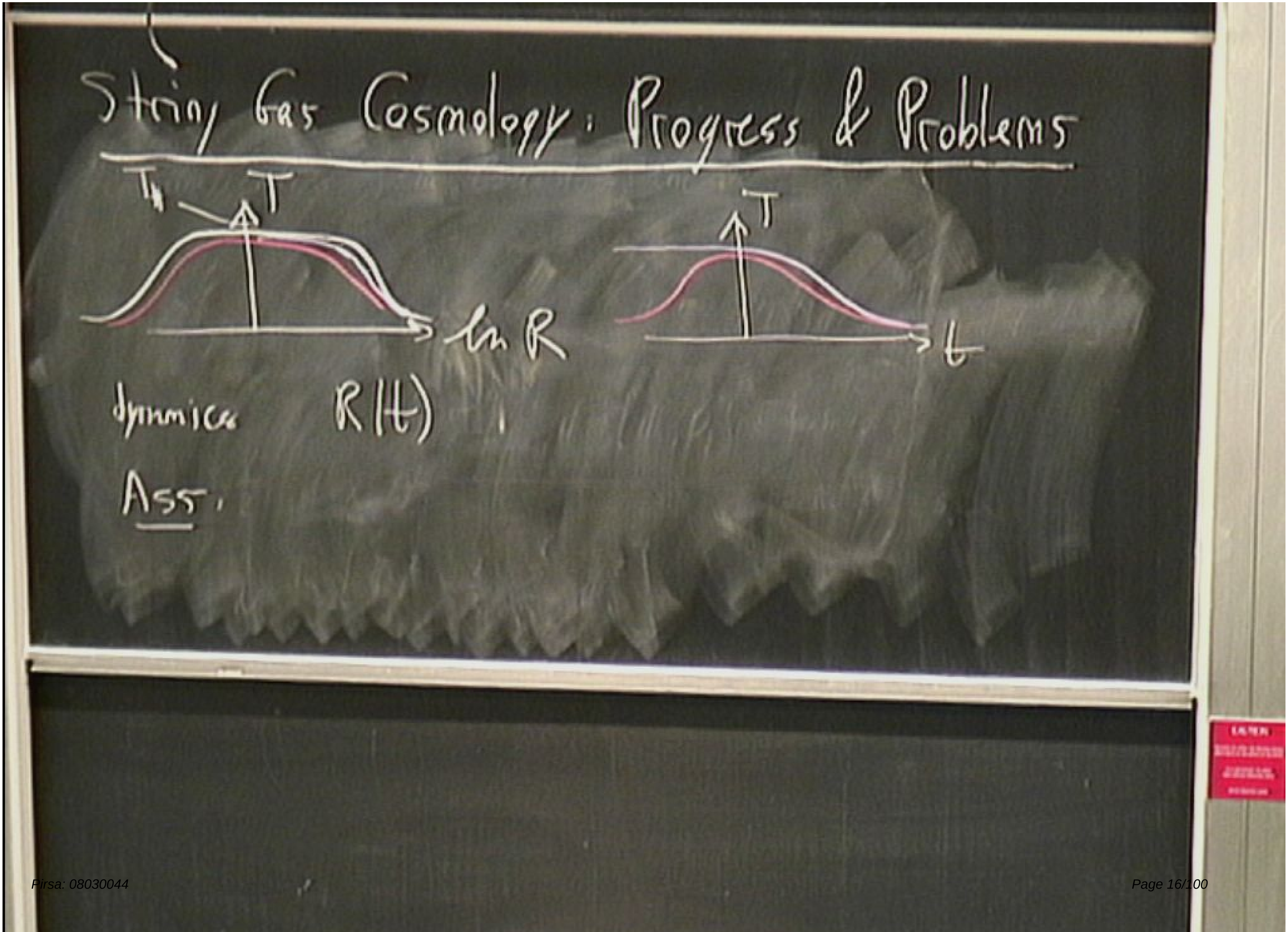
String Gas Cosmology: Progress & Problems

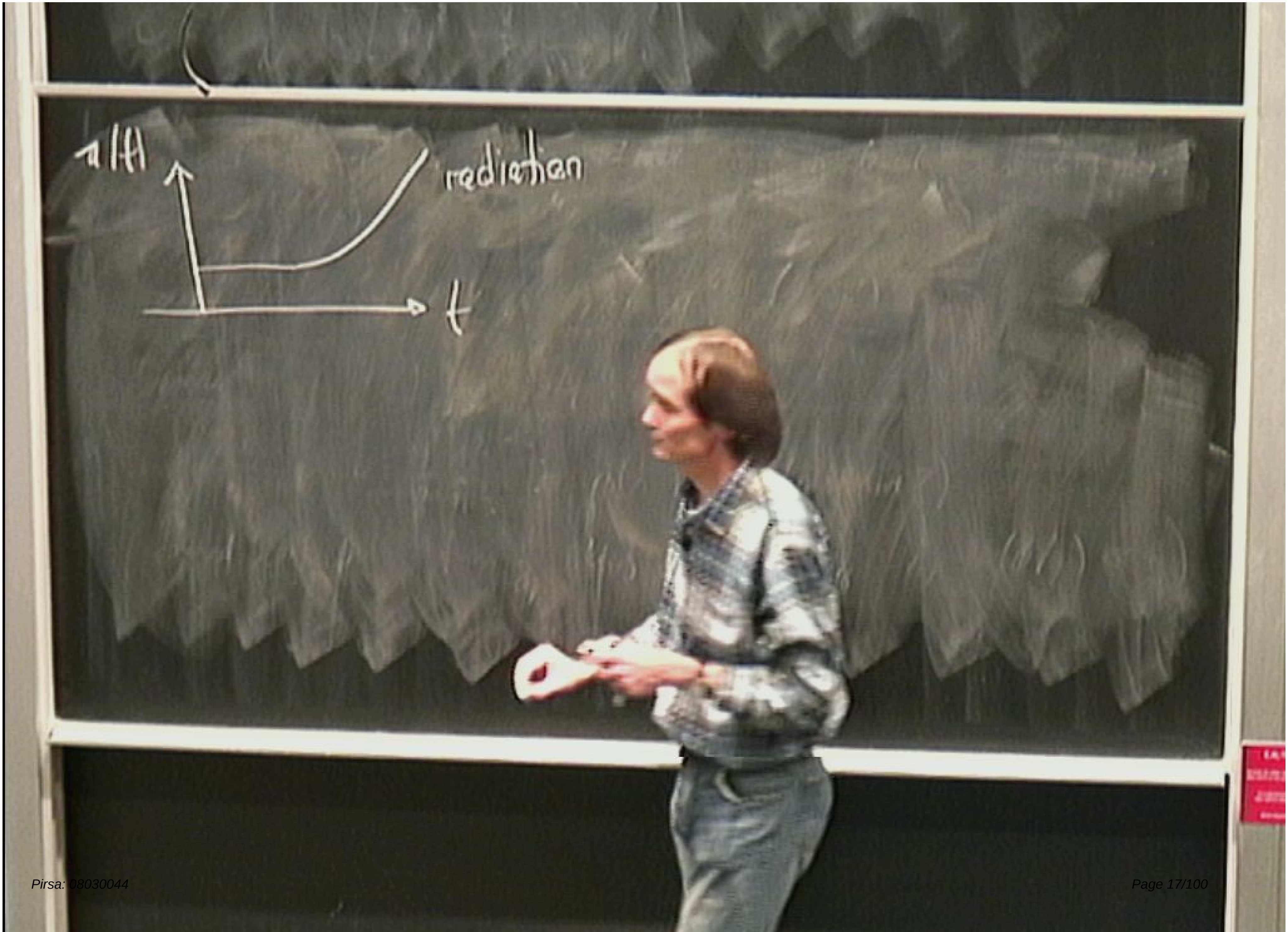


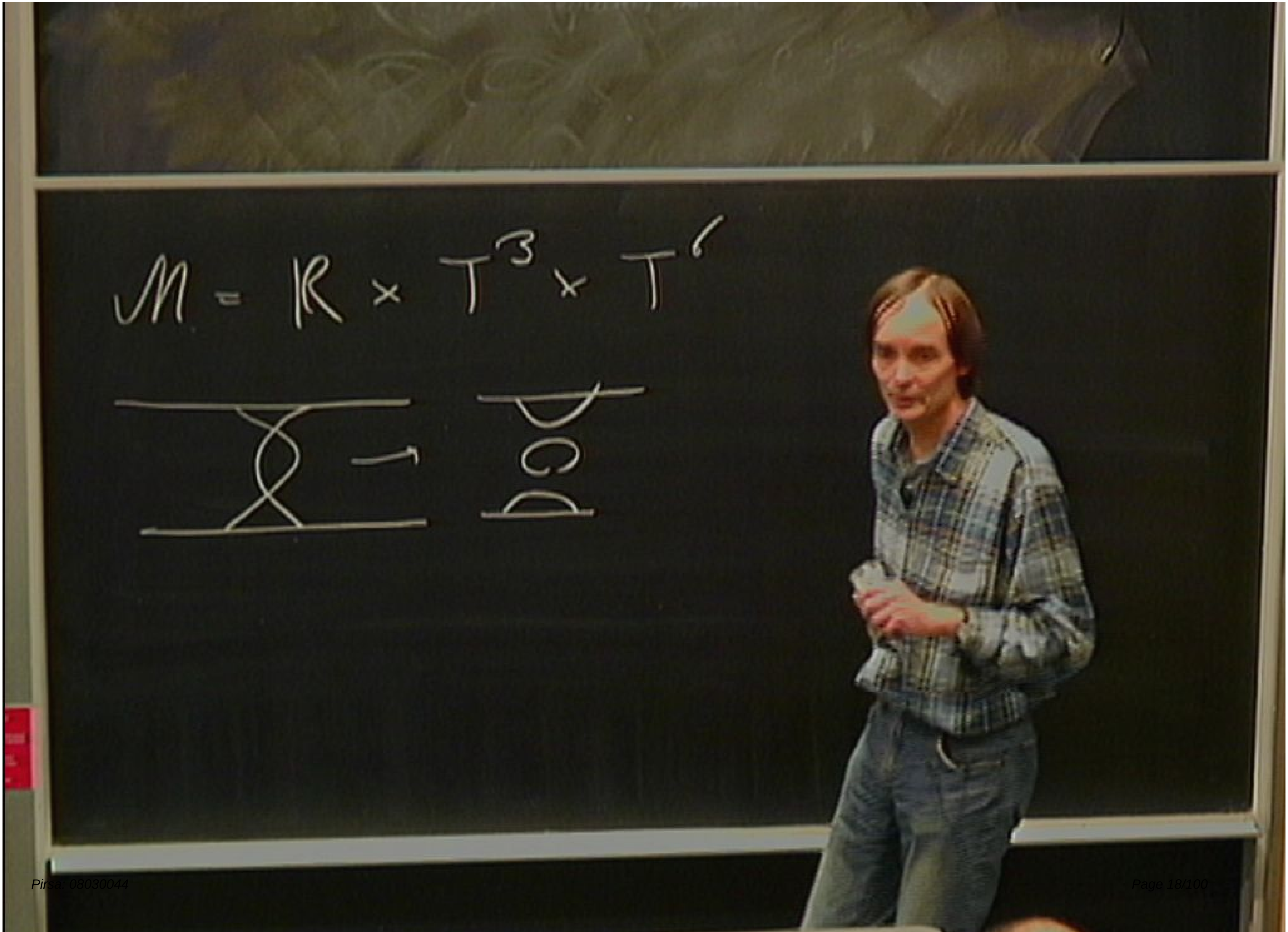


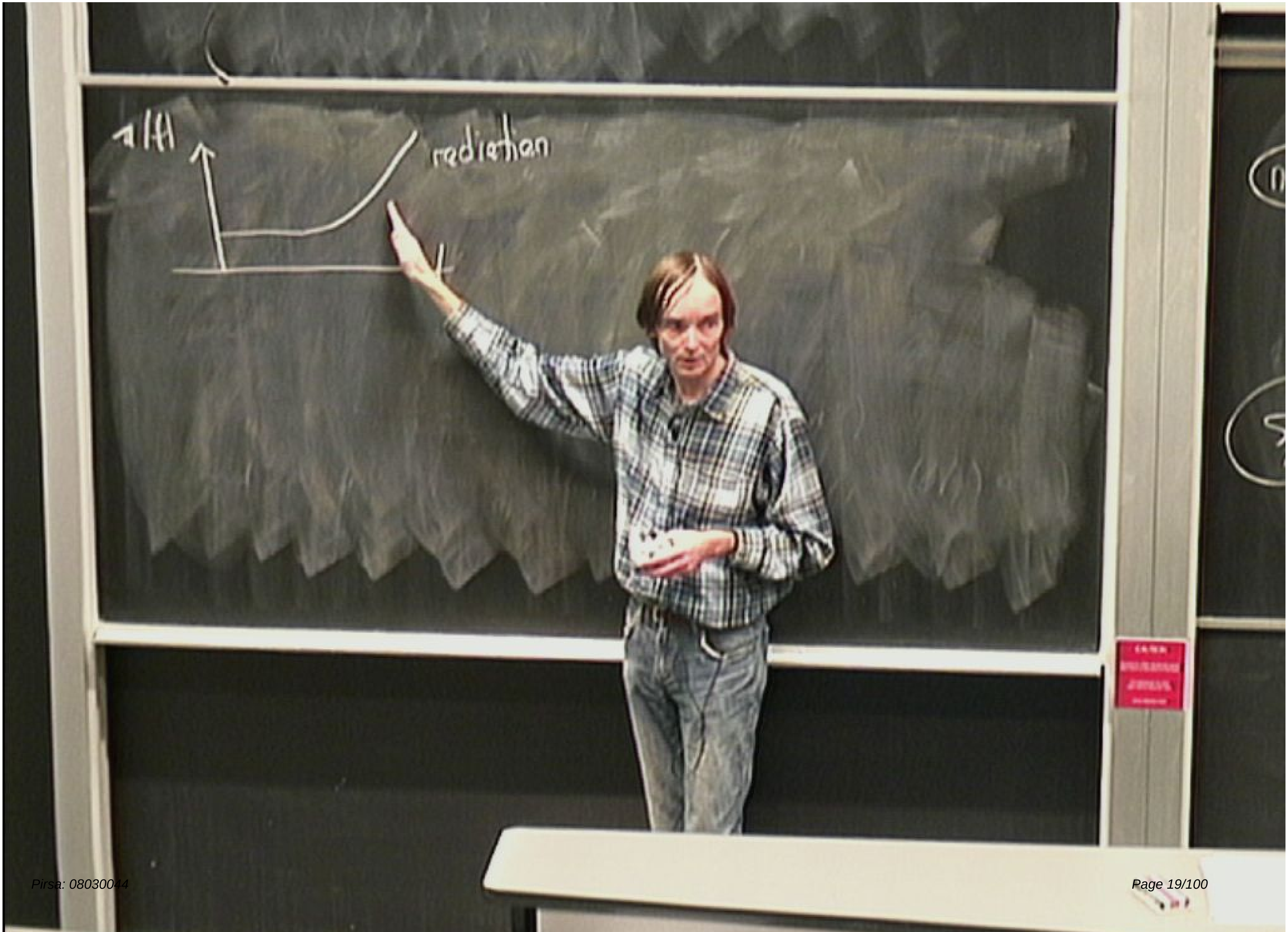
dynamics $R(t)$

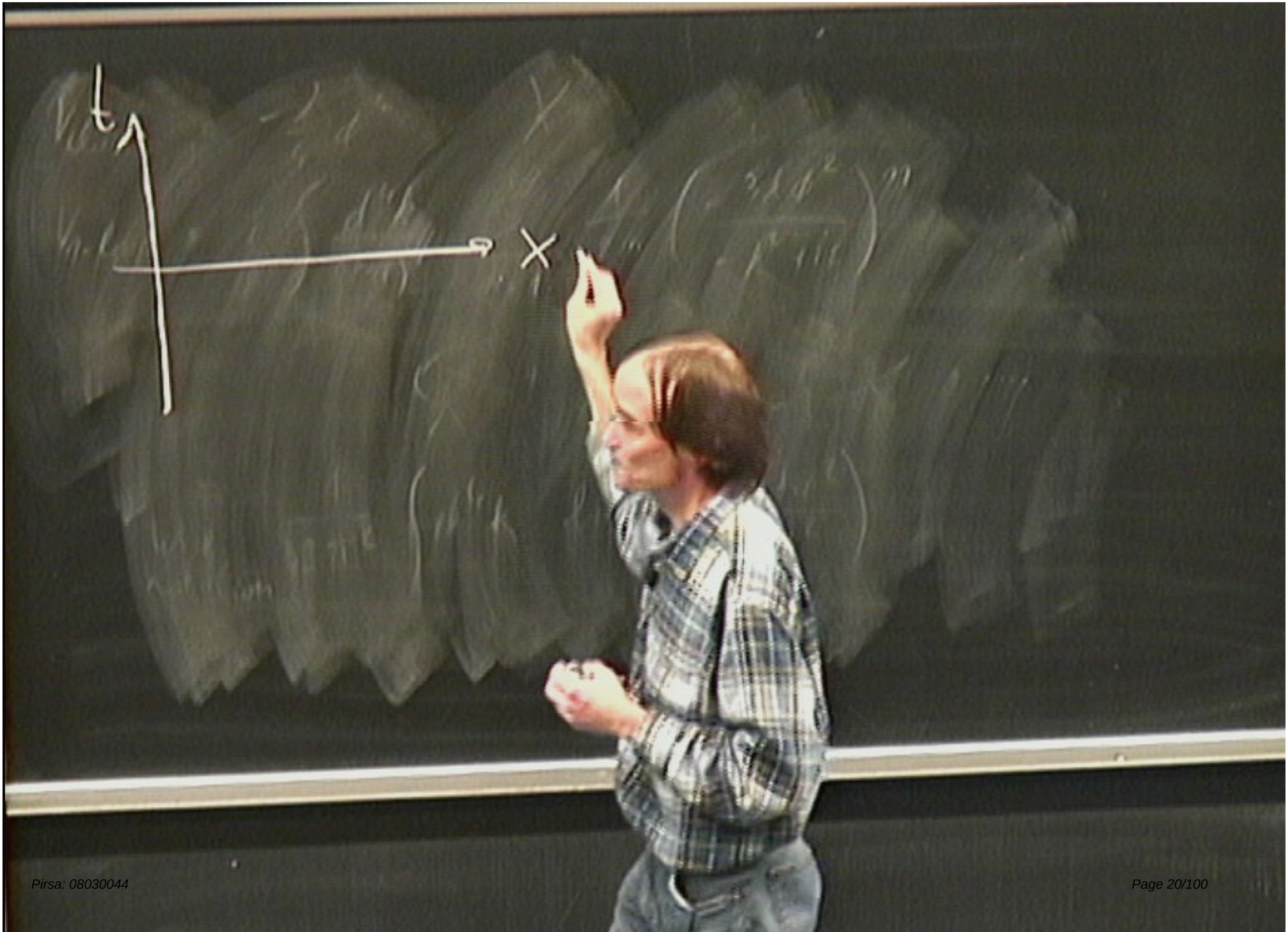

String Gas Cosmology: Progress & Problems
T_H
T
ln R
T
t
dynamics
R(t)

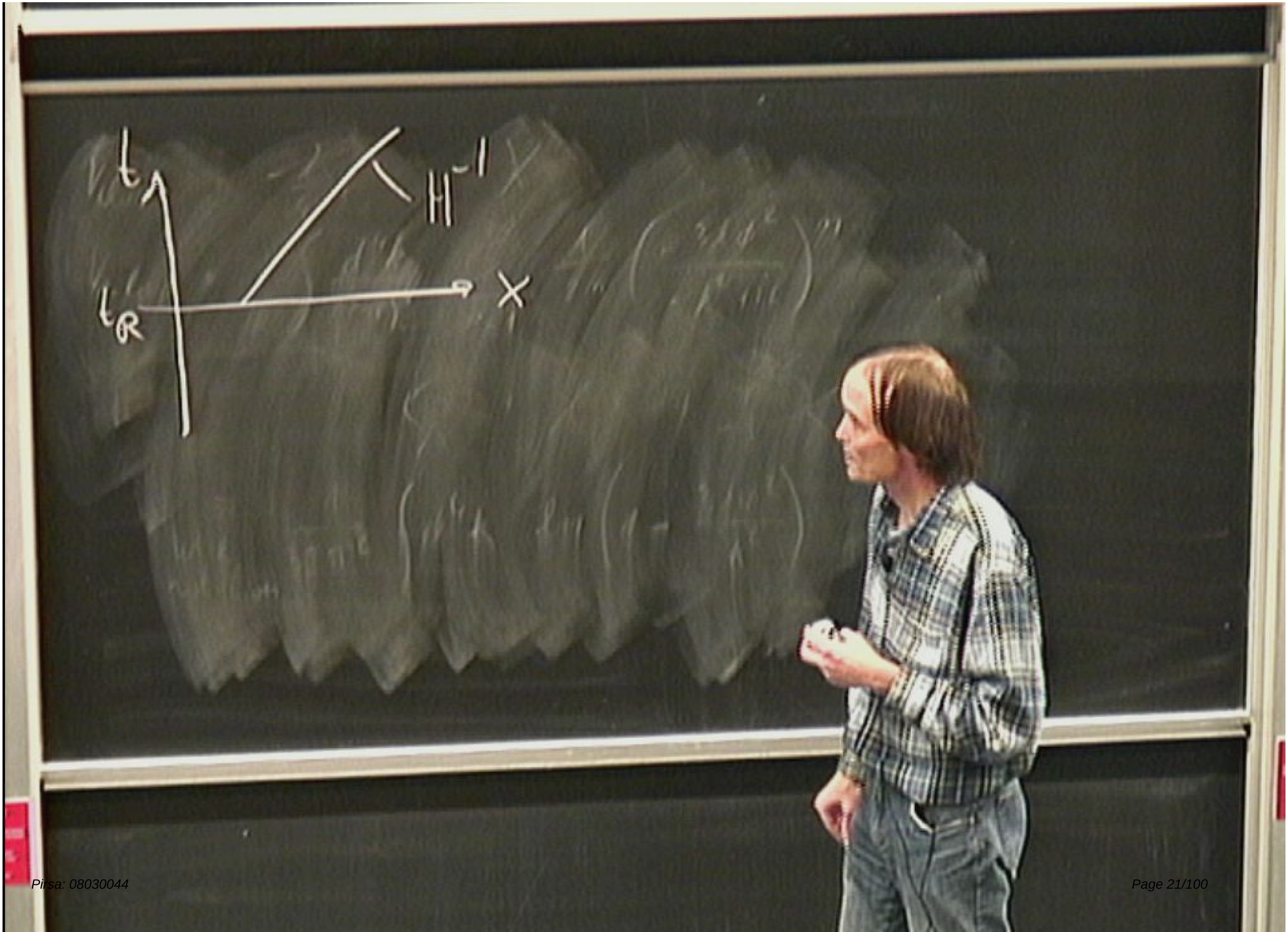

String Gas Cosmology: Progress & Problems
T_H
T
ln R
T
t
dynamical
R(t)
Ass.

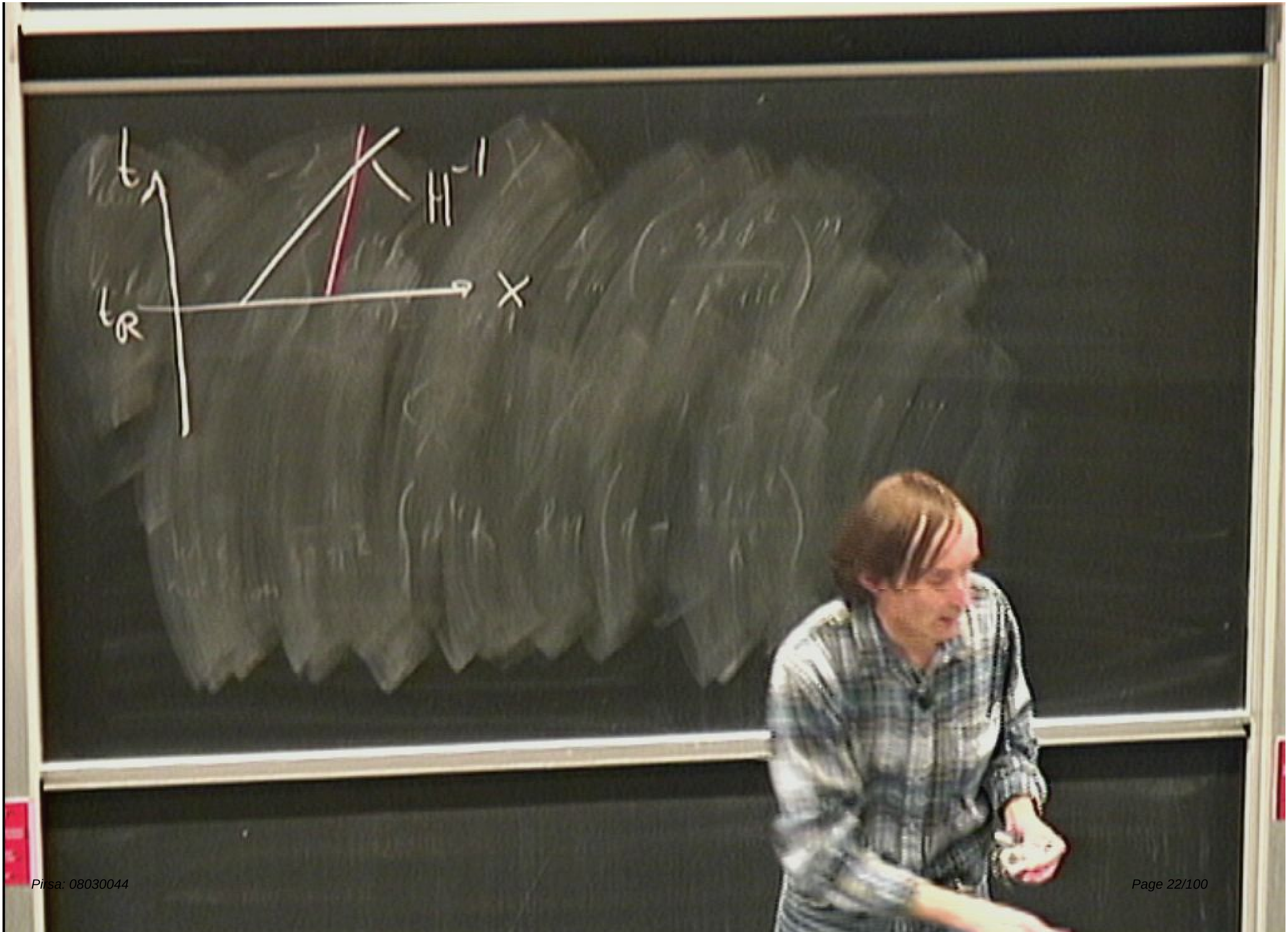

a(t)
radiation
t

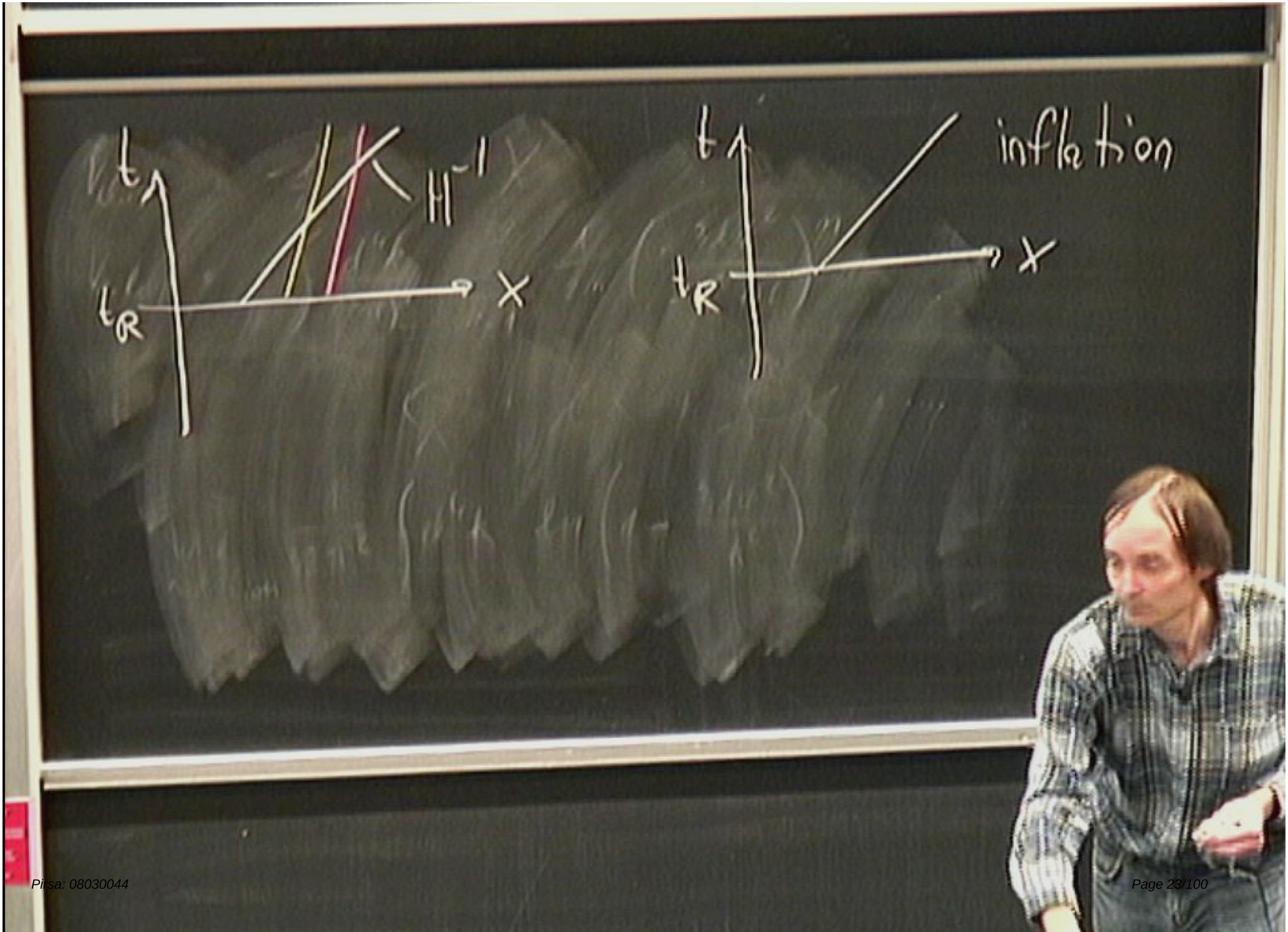

$\mathcal{M} = \mathbb{R} \times T^3 \times T^6$

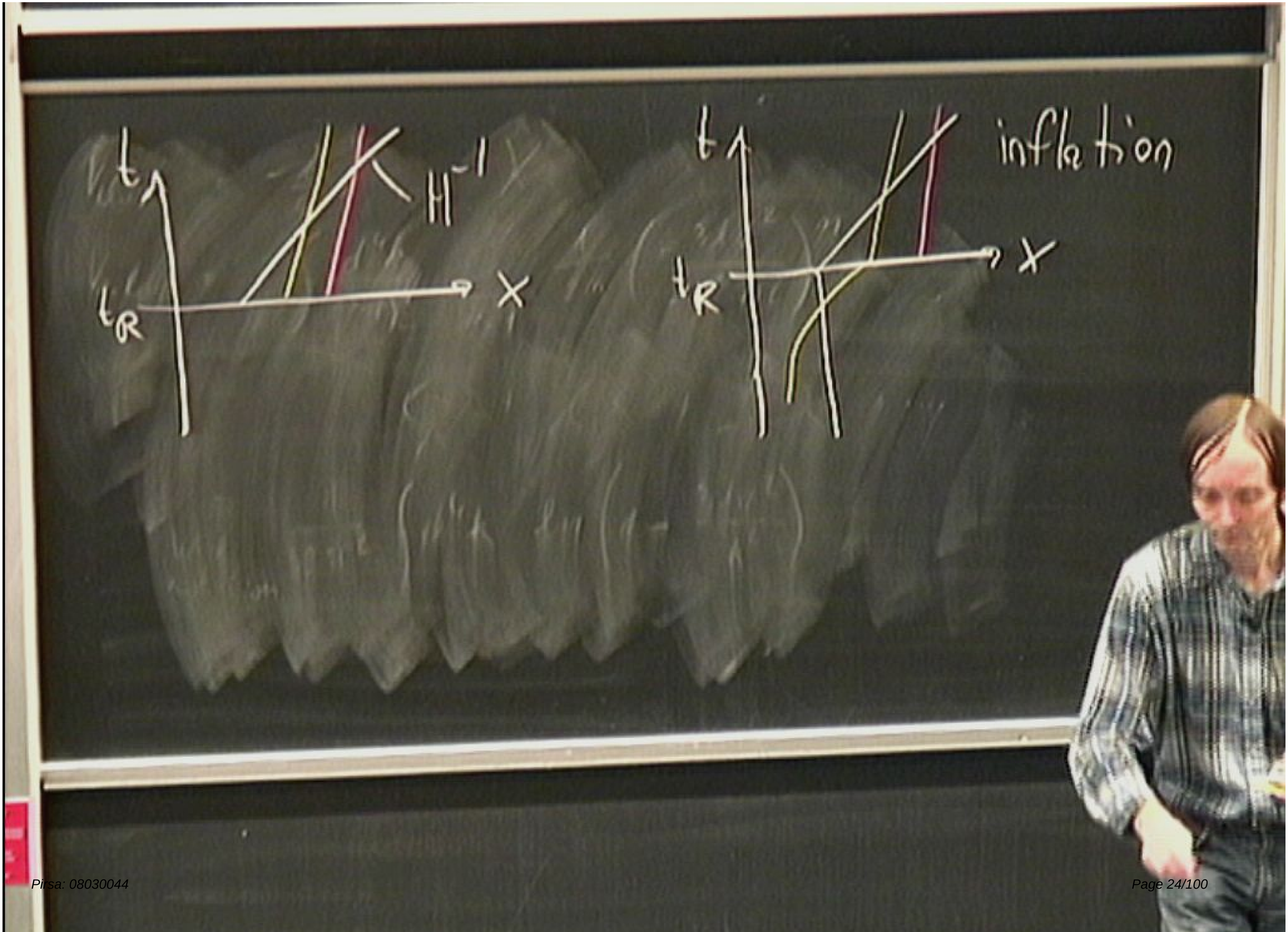

radiation

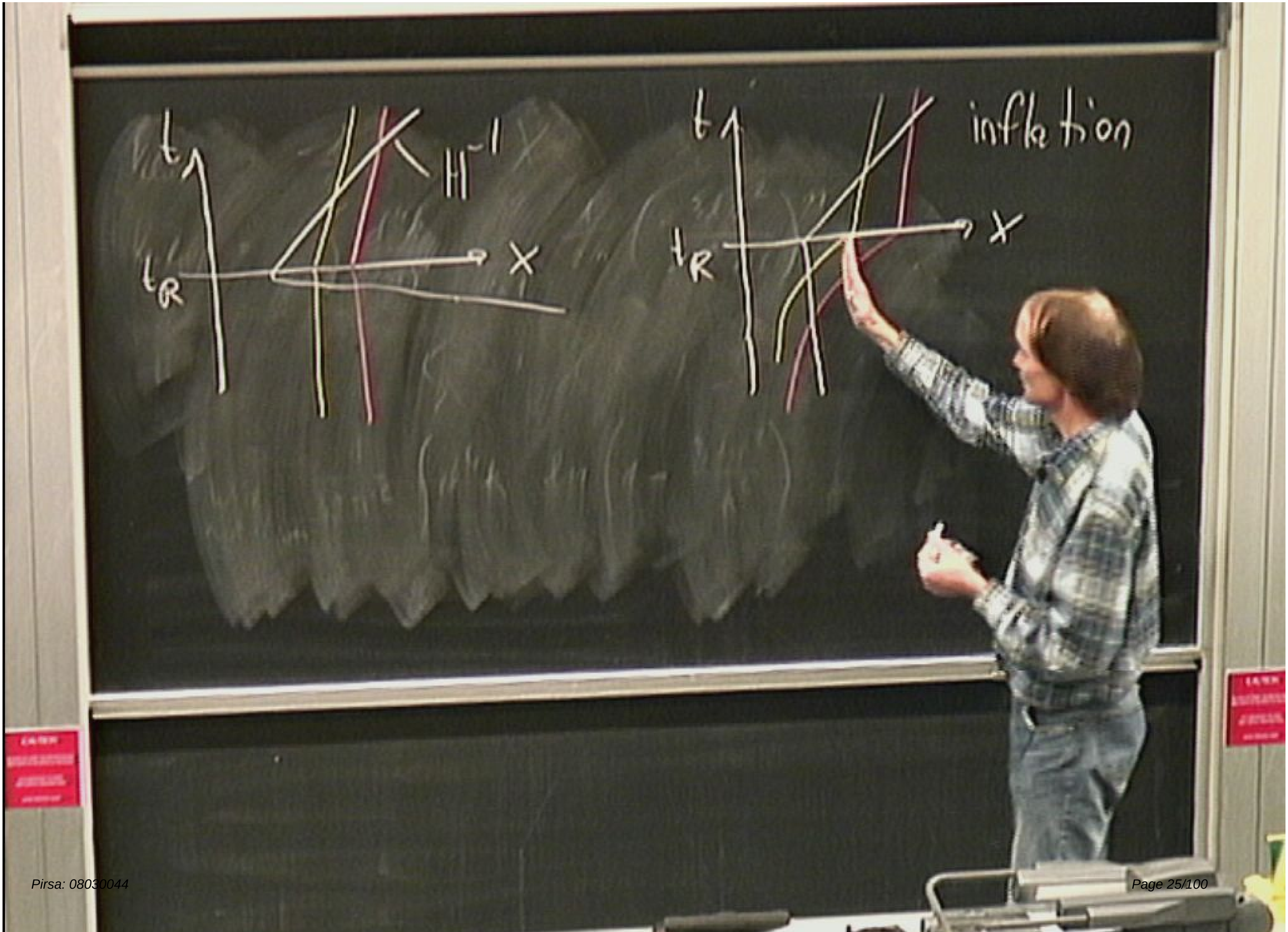

t
x

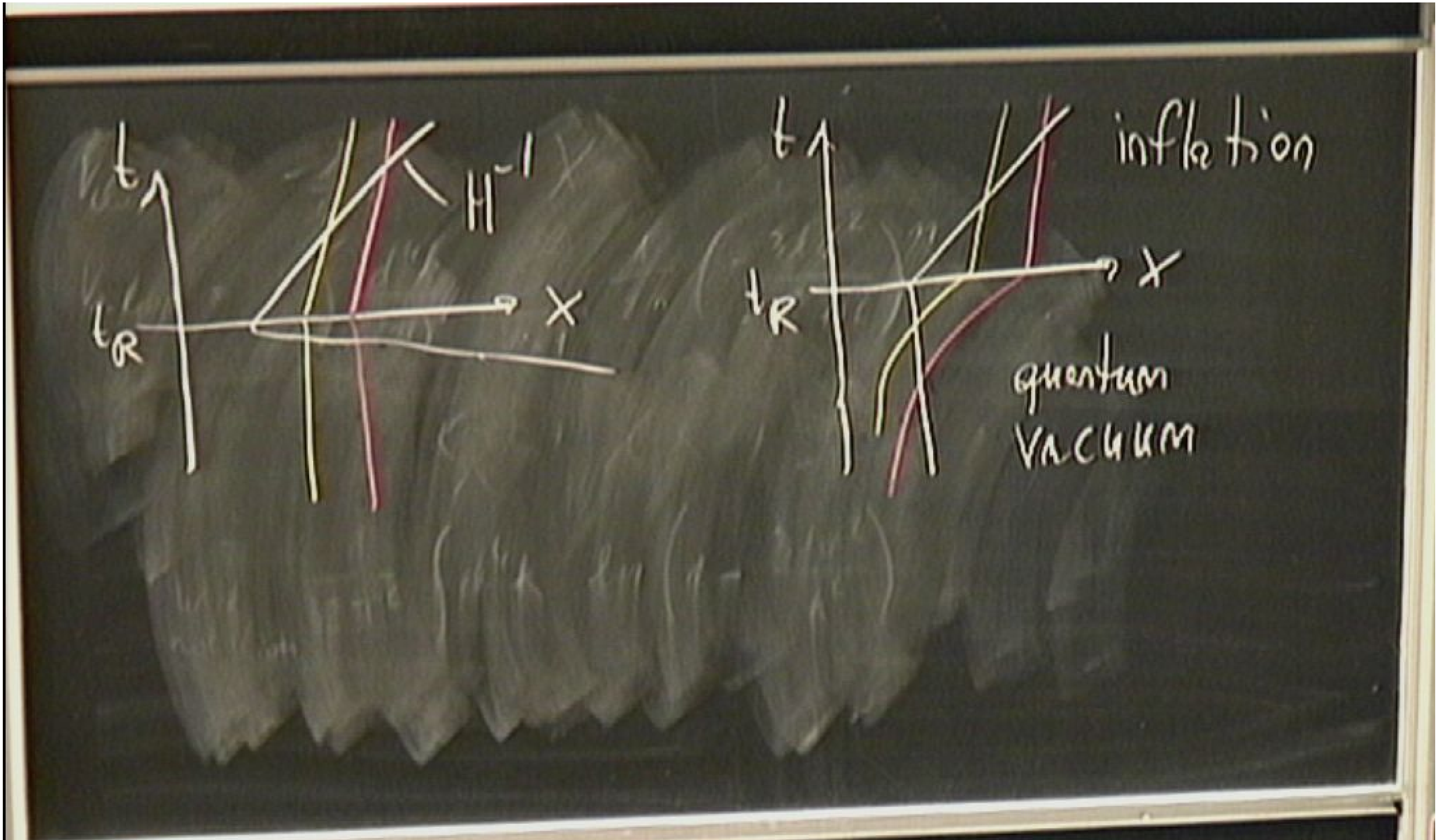

t
H^{-1}
t_R
x


t
H^{-1}
t_R
x

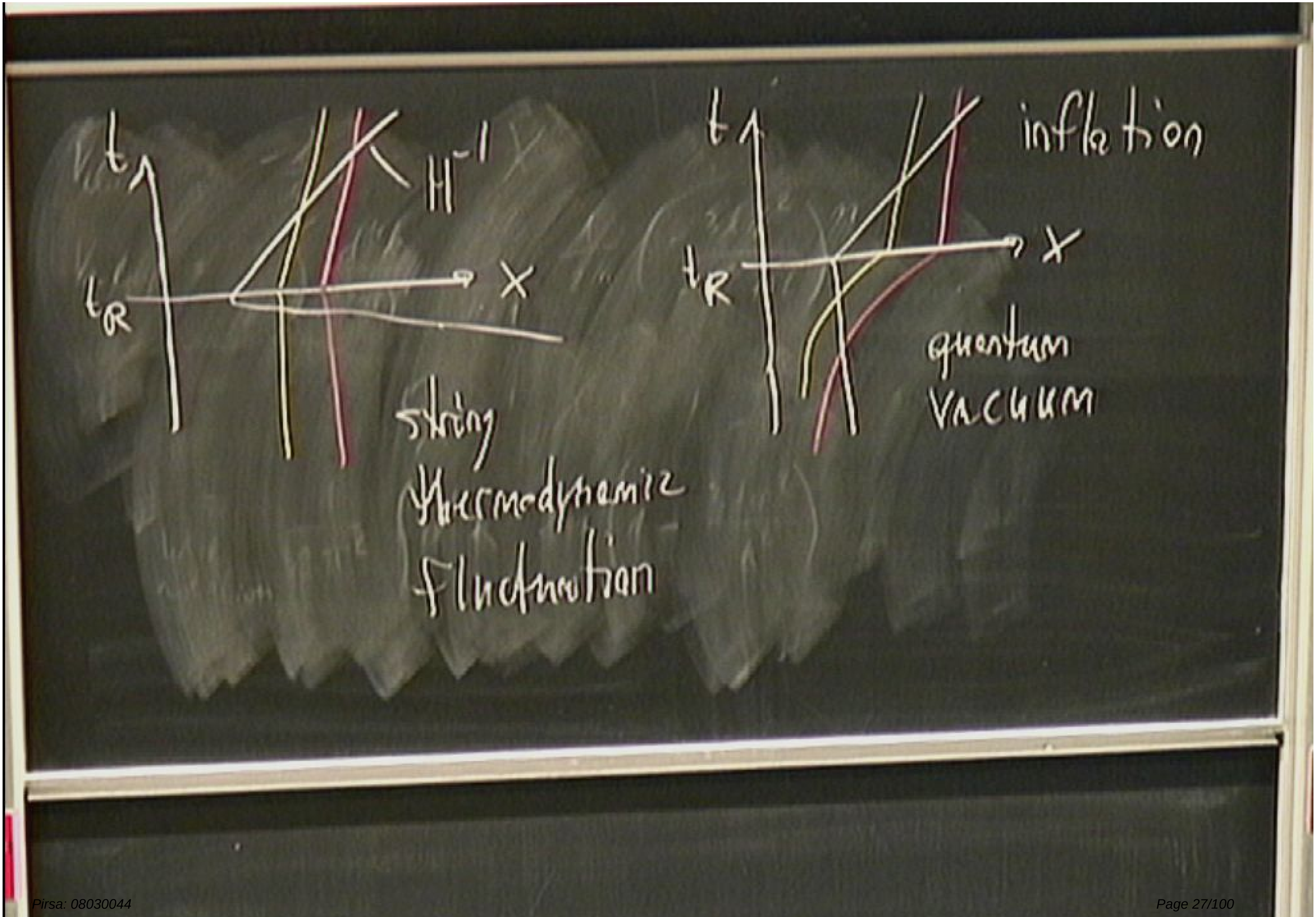

t
t_R
x
H^-1
t
t_R
x
inflation


t
H^{-1}
t_R
x
t
inflation
t_R
x

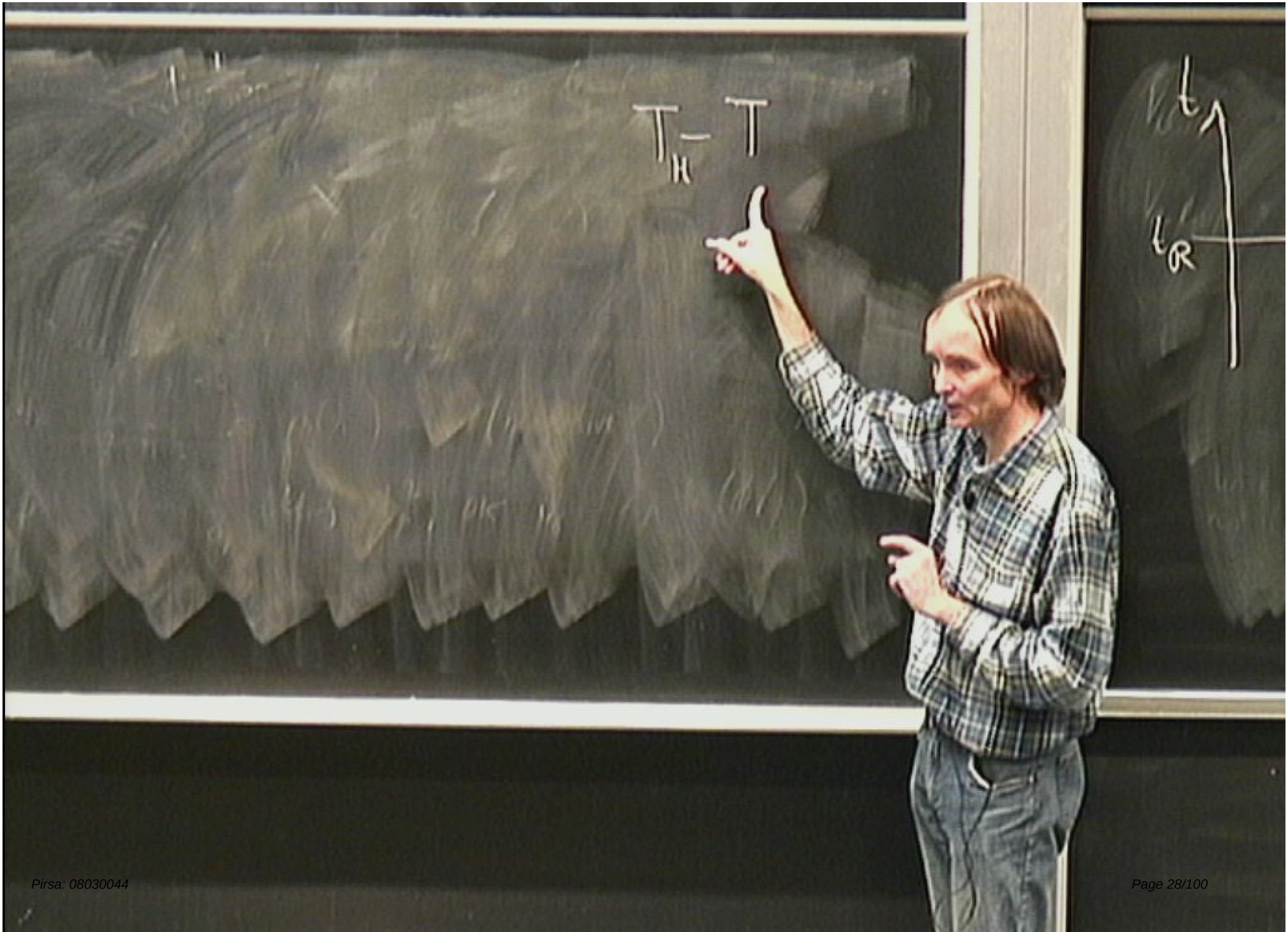

t
t_R
H^{-1}
x
t
t_R
x
inflation

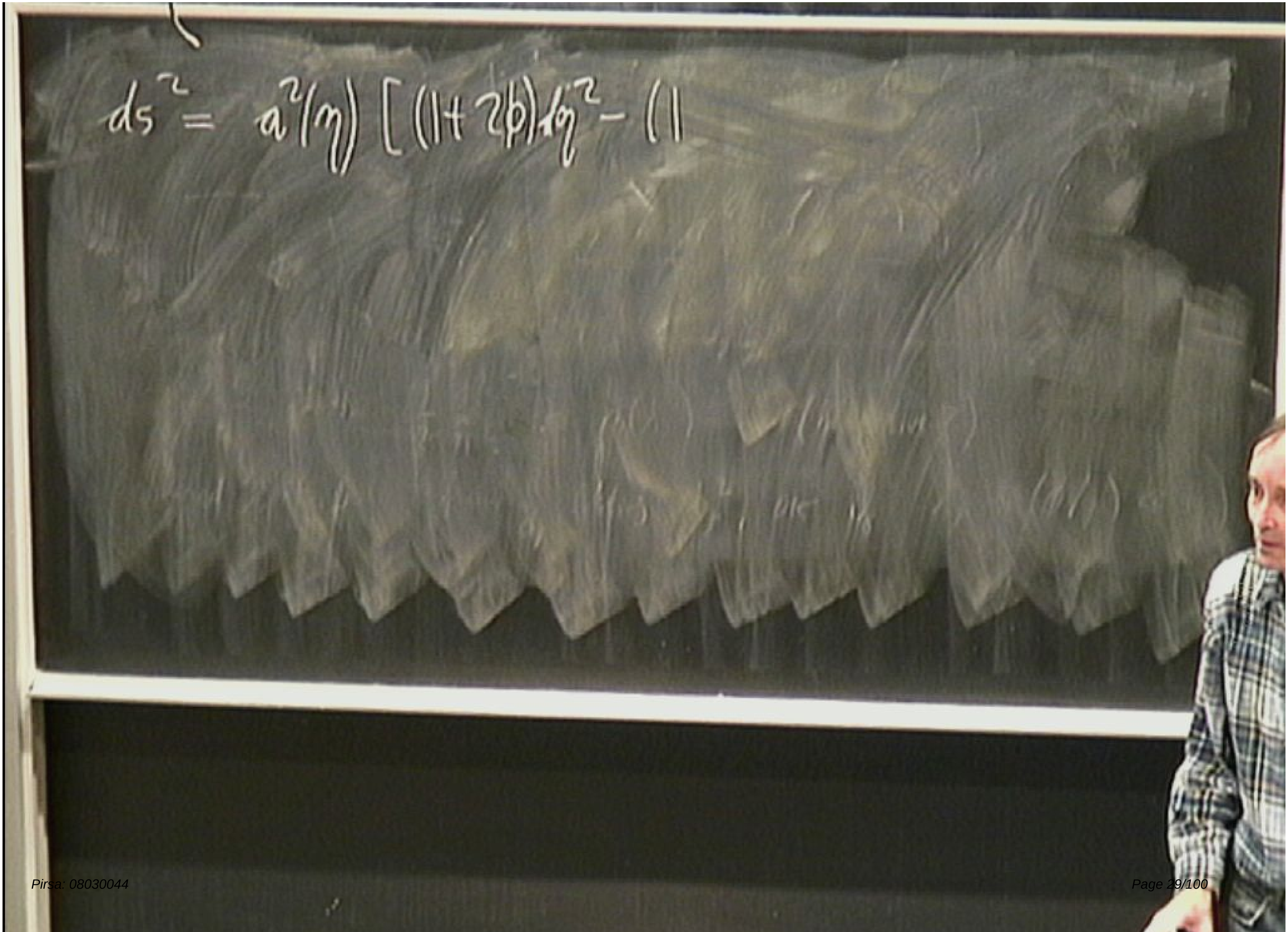


t
H^{-1}
t_R
x
t
inflation
t_R
x
quantum
vacuum



t
H^{-1}
t_R
x
string
thermodynamic
fluctuation
t
inflation
t_R
x
quantum
vacuum


$T_H - T$
t
t_R


$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - (1\right.$

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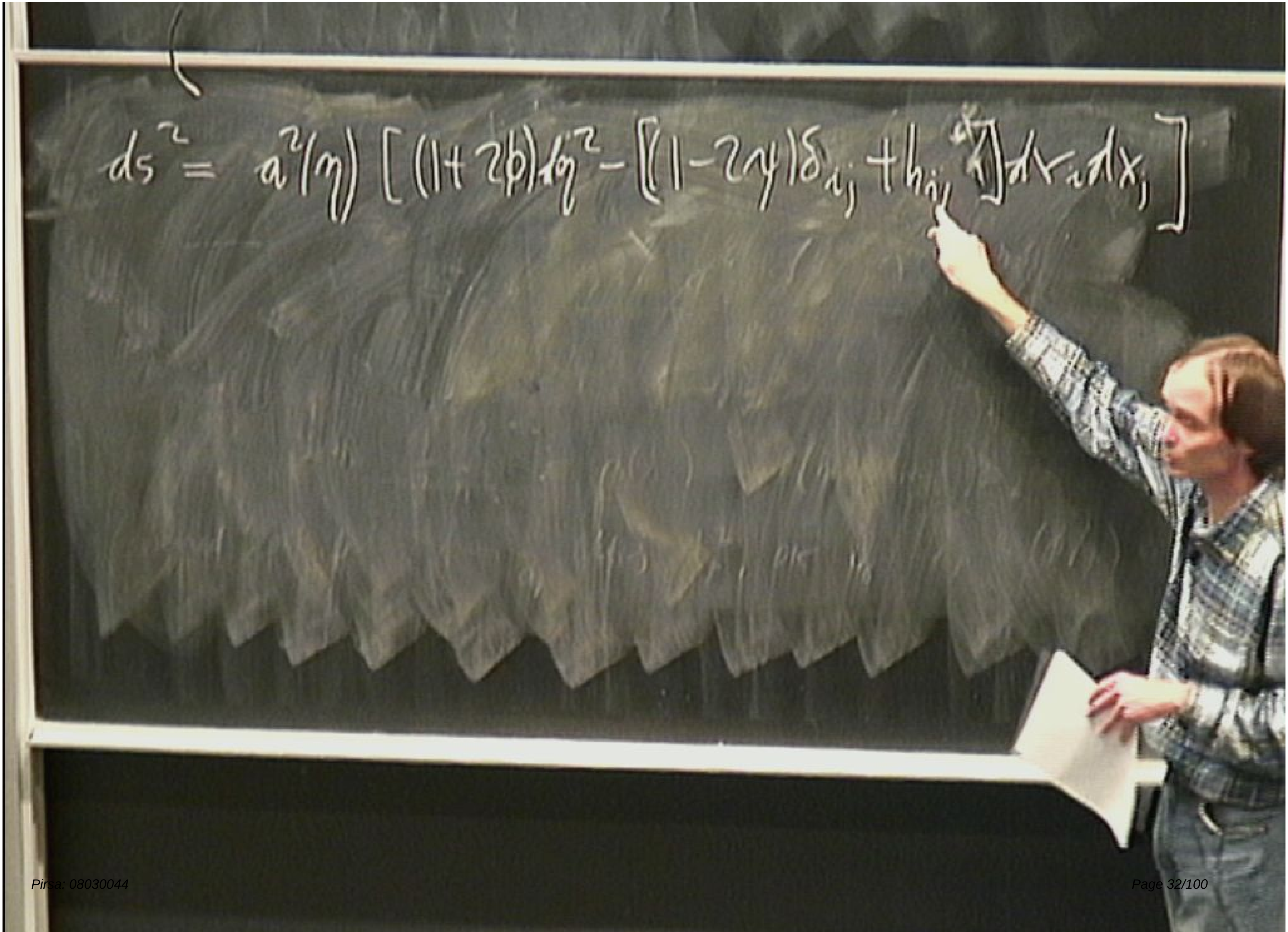
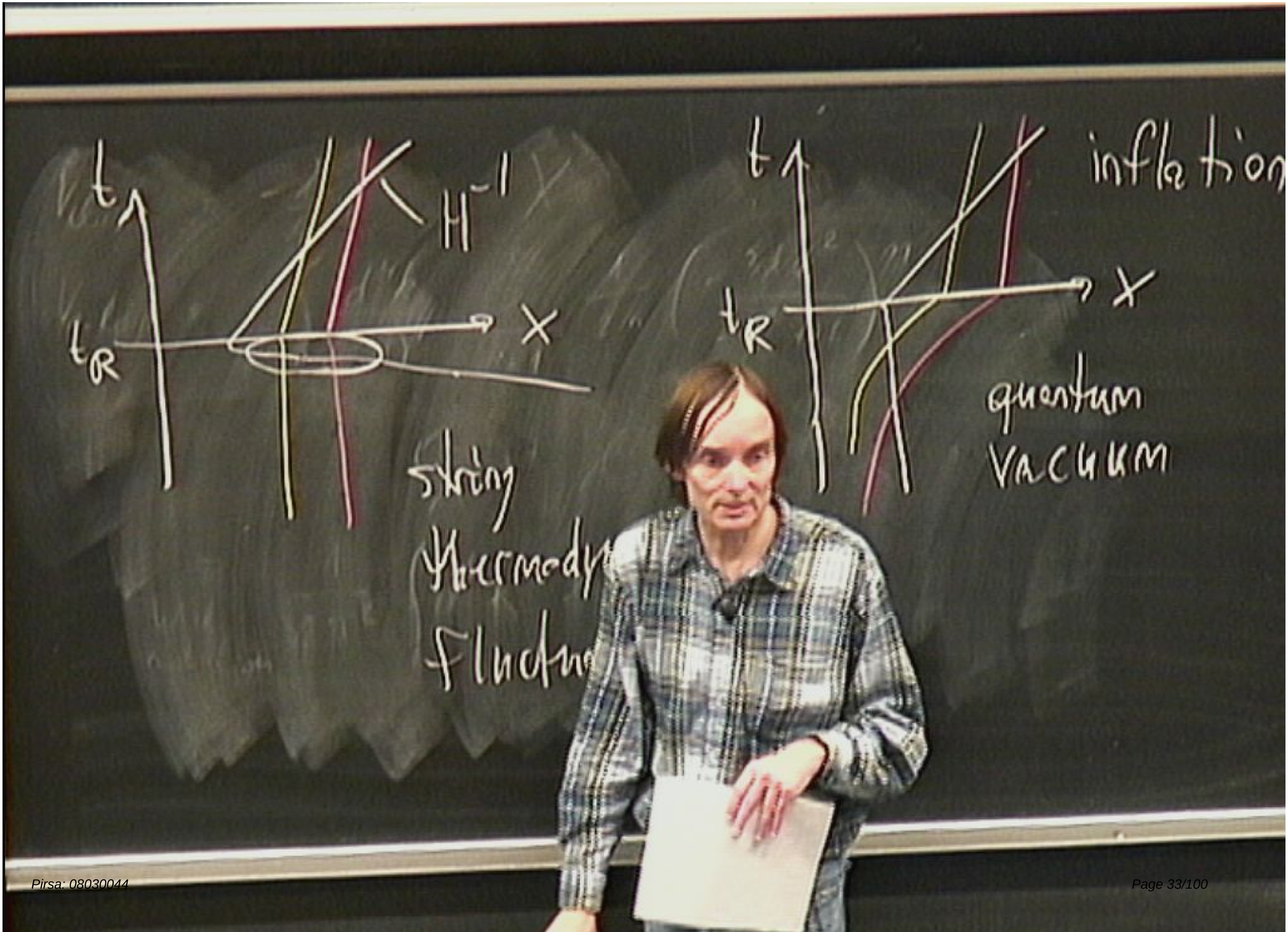
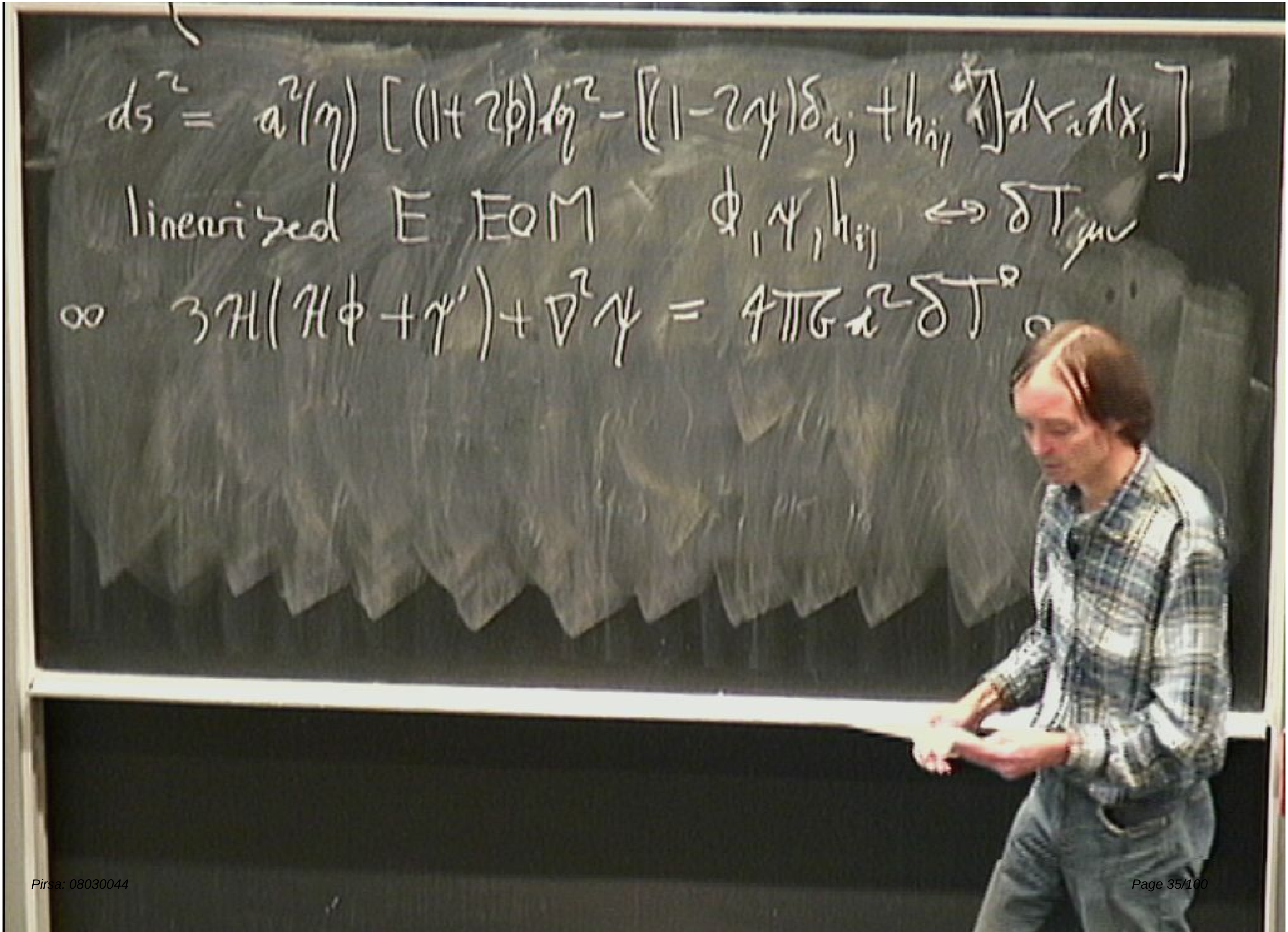
$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$$

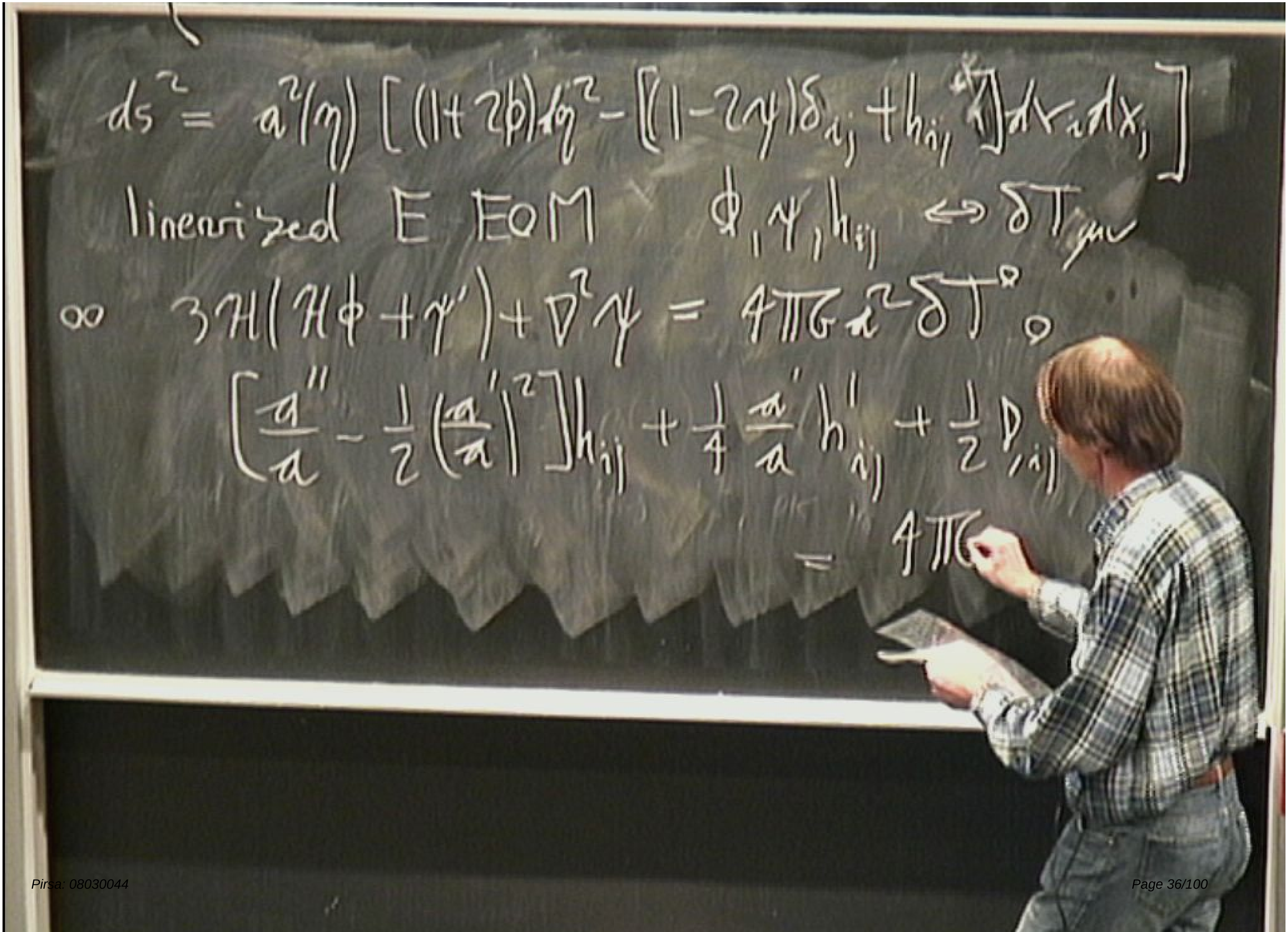

$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$


t
H^{-1}
x
t_R
string
t
t_R
x
inflation
quantum
vacuum

$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$$

linearized E EQM $\phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$


$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - \left[(1-2\psi)\delta_{ij} + h_{ij}\right]dx_i dx_j\right]$
linearized E EOM $\phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$
00 $3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0{}_0$


$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$
linearized E EOM $\phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$
00 $3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0{}_0$
$\left[\frac{a''}{a} - \frac{1}{2}\left(\frac{a'}{a}\right)^2\right]h_{ij} + \frac{1}{4}\frac{a'}{a}h'_{ij} + \frac{1}{2}D_{,ij}$
$= 4\pi G$

$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - \left[(1-2\psi)\delta_{ij} + h_{ij}\right]dx_i dx_j\right]$$

linearized E EOM $\phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$

$00 \quad 3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0{}_0$

$i \neq j \quad \left[\frac{a''}{a} - \frac{1}{2}\left(\frac{a'}{a}\right)^2\right]h_{ij} + \frac{1}{4}\frac{a'}{a}h'_{ij} + \frac{1}{2}D_{,ij}$

$$\left(\frac{\partial^2}{\partial\eta^2} - \nabla^2\right)h_{ij} = 4\pi G a^2 \delta T^i{}_j$$

$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$$

linearized E EOM $\phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$

$$\infty \quad 3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0{}_0 \qquad ' = \frac{\partial}{\partial\eta}$$

$$i \neq j \quad \left[\frac{a''}{a} - \frac{1}{2}\left(\frac{a'}{a}\right)^2\right]h_{ij} + \frac{1}{4}\frac{a'}{a}h'_{ij} + \frac{1}{2}D_{,ij}$$

$$\left(\frac{\partial^2}{\partial\eta^2} - \nabla^2\right)h_{ij} = 4\pi G a^2 \delta T^i{}_j$$

$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - \left[(1-2\psi)\delta_{ij} + h_{ij}\right]dx_i dx_j\right]$$

linearized E EOM $\quad \phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$

$$00 \quad 3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0{}_0 \qquad ' = \frac{\partial}{\partial\eta}$$

$$i \neq j \quad \left[\frac{a''}{a} - \frac{1}{2}\left(\frac{a'}{a}\right)^2\right]h_{ij} + \frac{1}{4}\frac{a'}{a}h'_{ij} + \frac{1}{2}D_{,ij}$$

$$\left(\frac{\partial^2}{\partial\eta^2} - \nabla^2\right)h_{ij} = 4\pi G a^2 \delta T^i{}_j$$

$$D = \phi - \psi'$$

$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$$

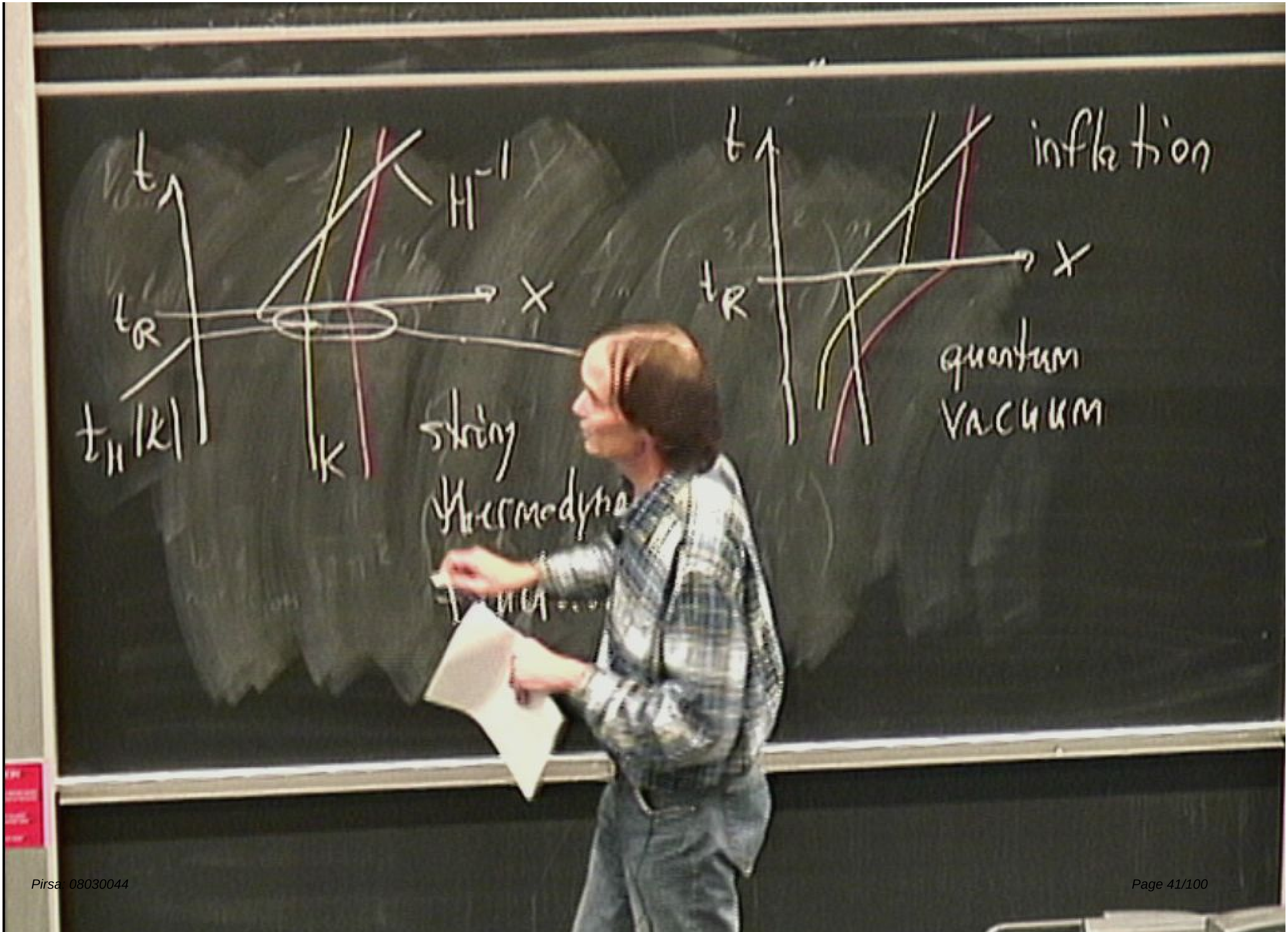
linearized E. EOM $\phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$

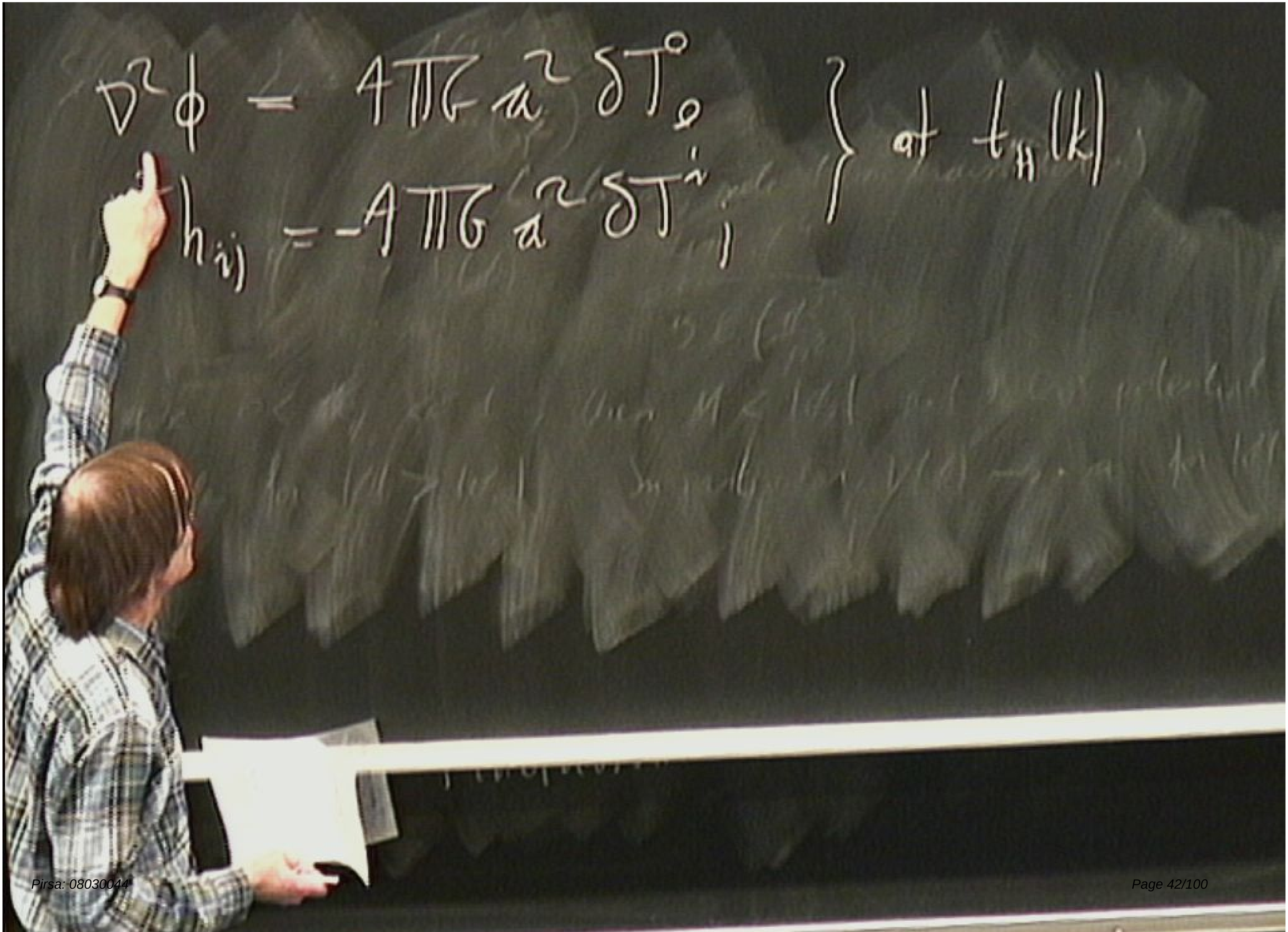
$00 \quad 3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0{}_0 \qquad ' = \frac{\partial}{\partial\eta}$

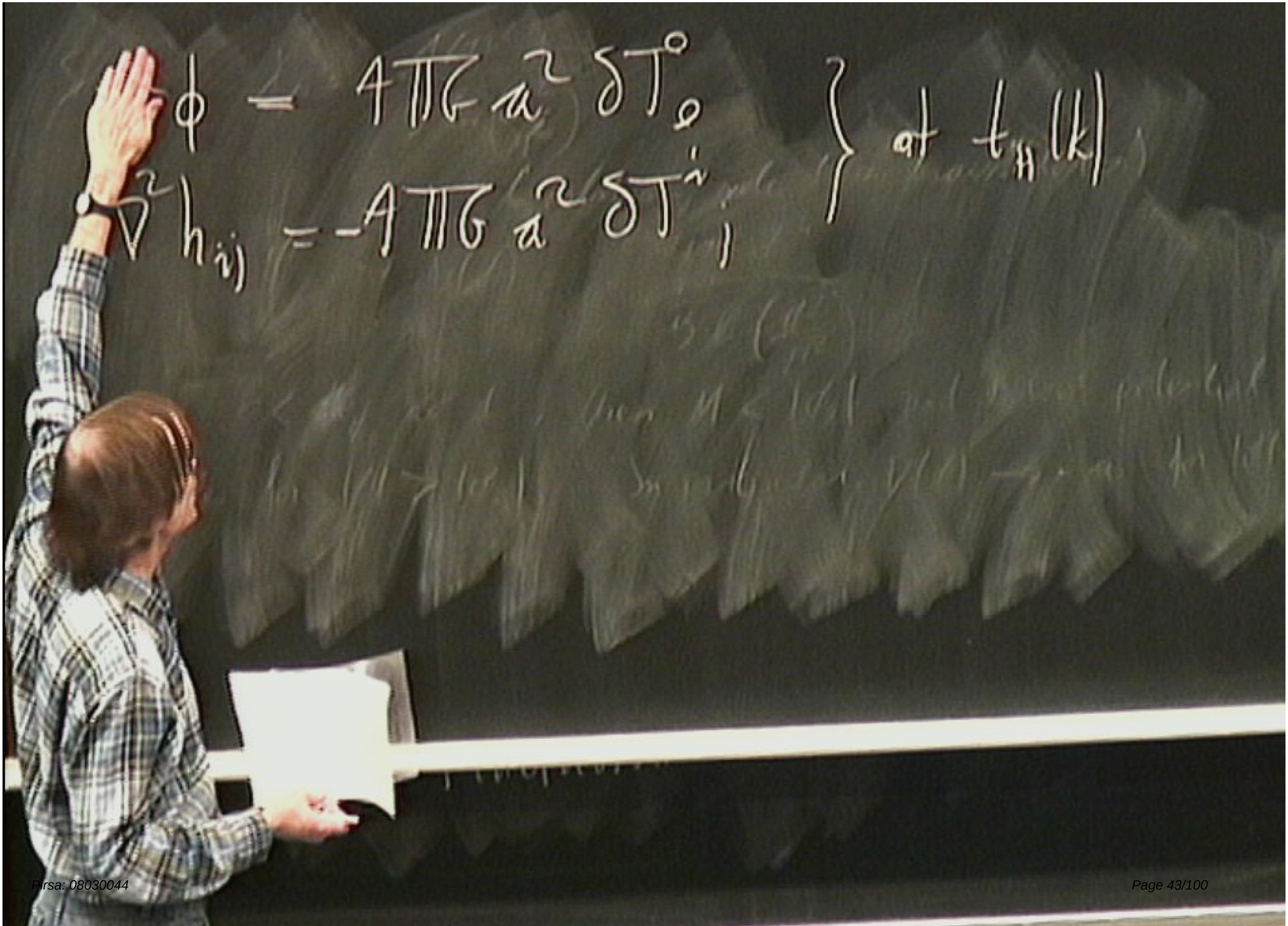
$$i\neq j \quad \left[\frac{a''}{a} - \frac{1}{2}\left(\frac{a'}{a}\right)^2\right]h_{ij} + \frac{1}{4}\frac{a'}{a}h'_{ij} + \frac{1}{2}D_{,ij}$$

$$\left(\frac{\partial^2}{\partial\eta^2} - \nabla^2\right)h_{ij} = 4\pi G a^2 \delta T^i{}_j$$

$D = \phi - \psi$


t
H^-1
x
t_R
t_H |k|
k
string
t
x
t_R
inflation
quantum
vacuum


$\nabla^2\phi = 4\pi G a^2 \delta T^0_0$
$h_{ij} = -4\pi G a^2 \delta T^i_j$
at $t_H(k)$


$\phi = 4\pi G a^2 \delta T^0_0$
$\nabla^2 h_{ij} = -4\pi G a^2 \delta T^i_j$
at $t_H(k)$

$$ds^2 = a^2(\eta)\left[(1+2\phi)d\eta^2 - [(1-2\psi)\delta_{ij} + h_{ij}]dx_i dx_j\right]$$

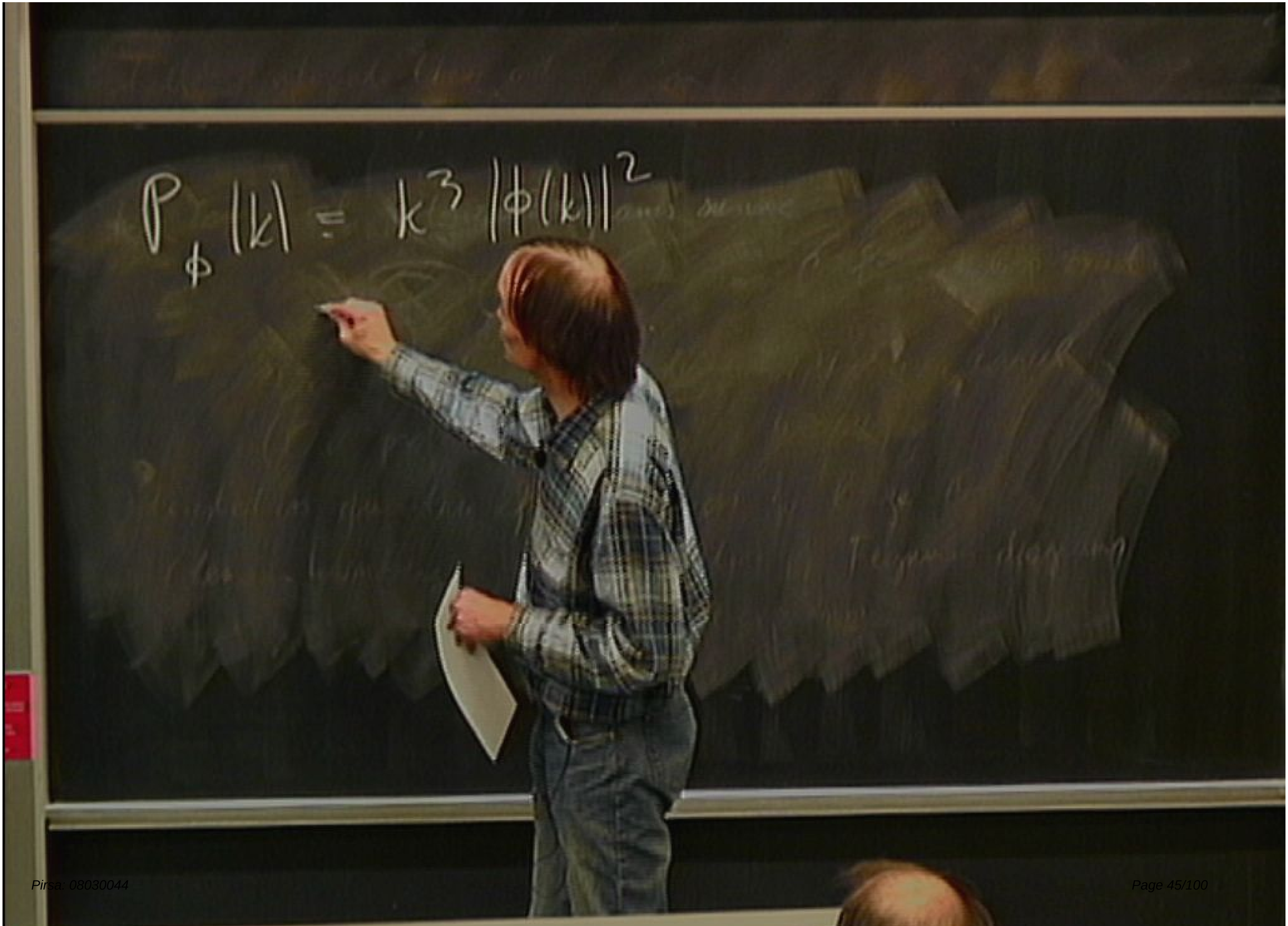
linearized E EOM $\quad \phi, \psi, h_{ij} \Leftrightarrow \delta T_{\mu\nu}$

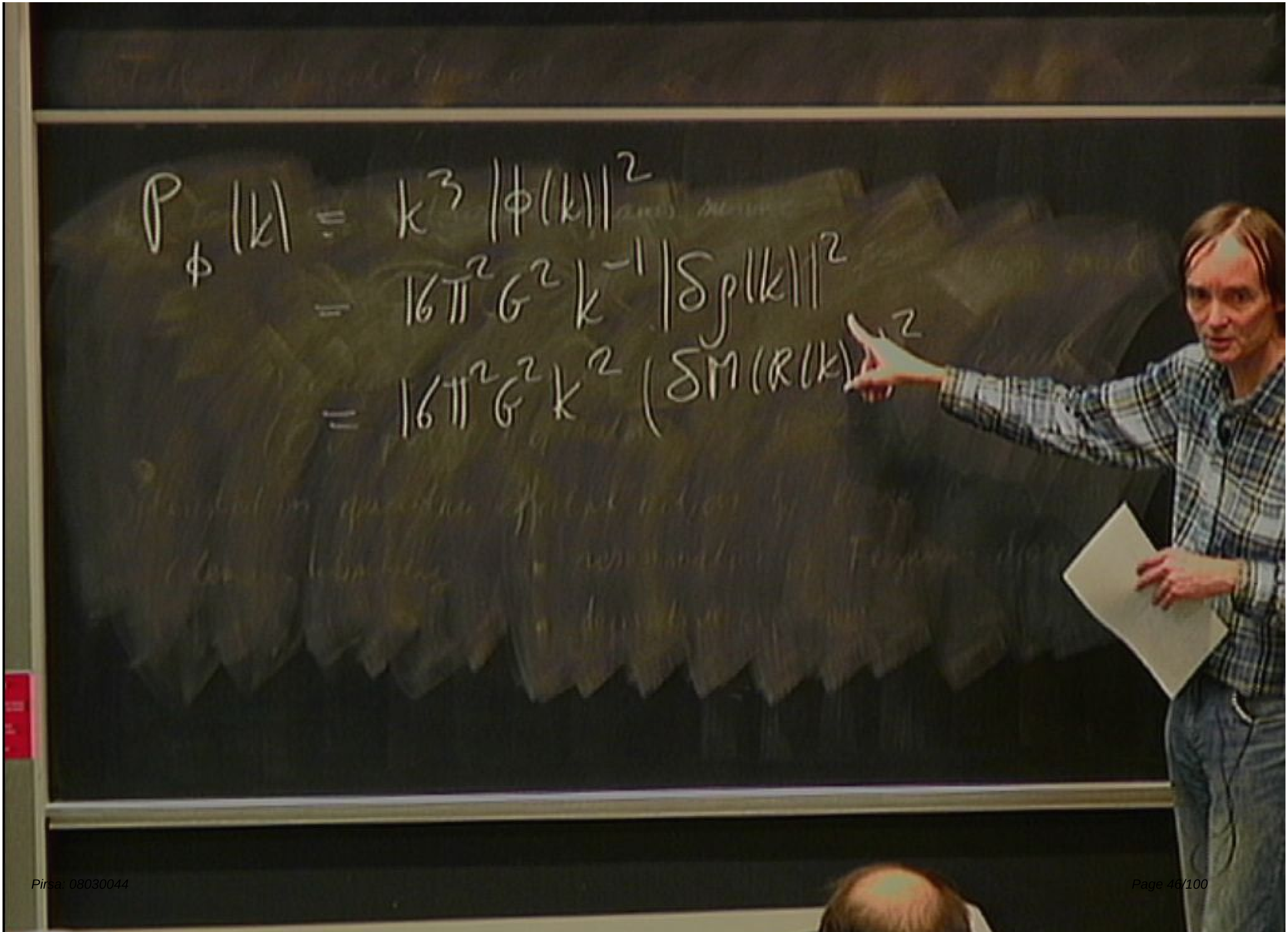
$$00 \quad 3\mathcal{H}(\mathcal{H}\phi + \psi') + \nabla^2\psi = 4\pi G a^2 \delta T^0_0 \qquad ' = \frac{\partial}{\partial\eta}$$

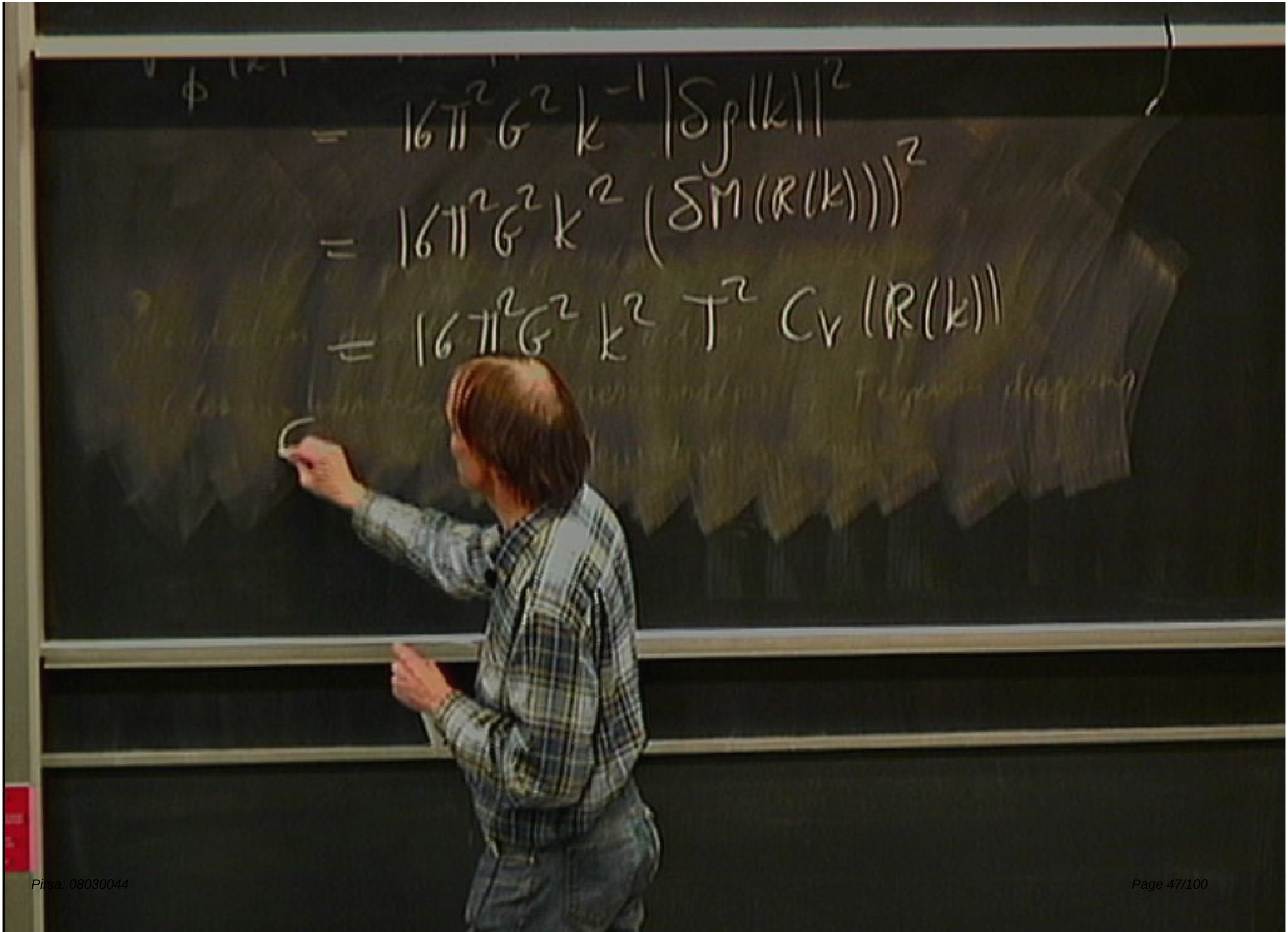
$$i \neq j \quad \left[\frac{a''}{a} - \frac{1}{2}\left(\frac{a'}{a}\right)^2\right]h_{ij} + \frac{1}{4}\frac{a'}{a}h'_{ij} + \frac{1}{2}D_{,ij} = 4\pi G a^2 \delta T^i_j$$

$$\mathcal{H} = k \qquad \left(\frac{\partial^2}{\partial\eta^2} - \nabla^2\right)h_{ij} =$$

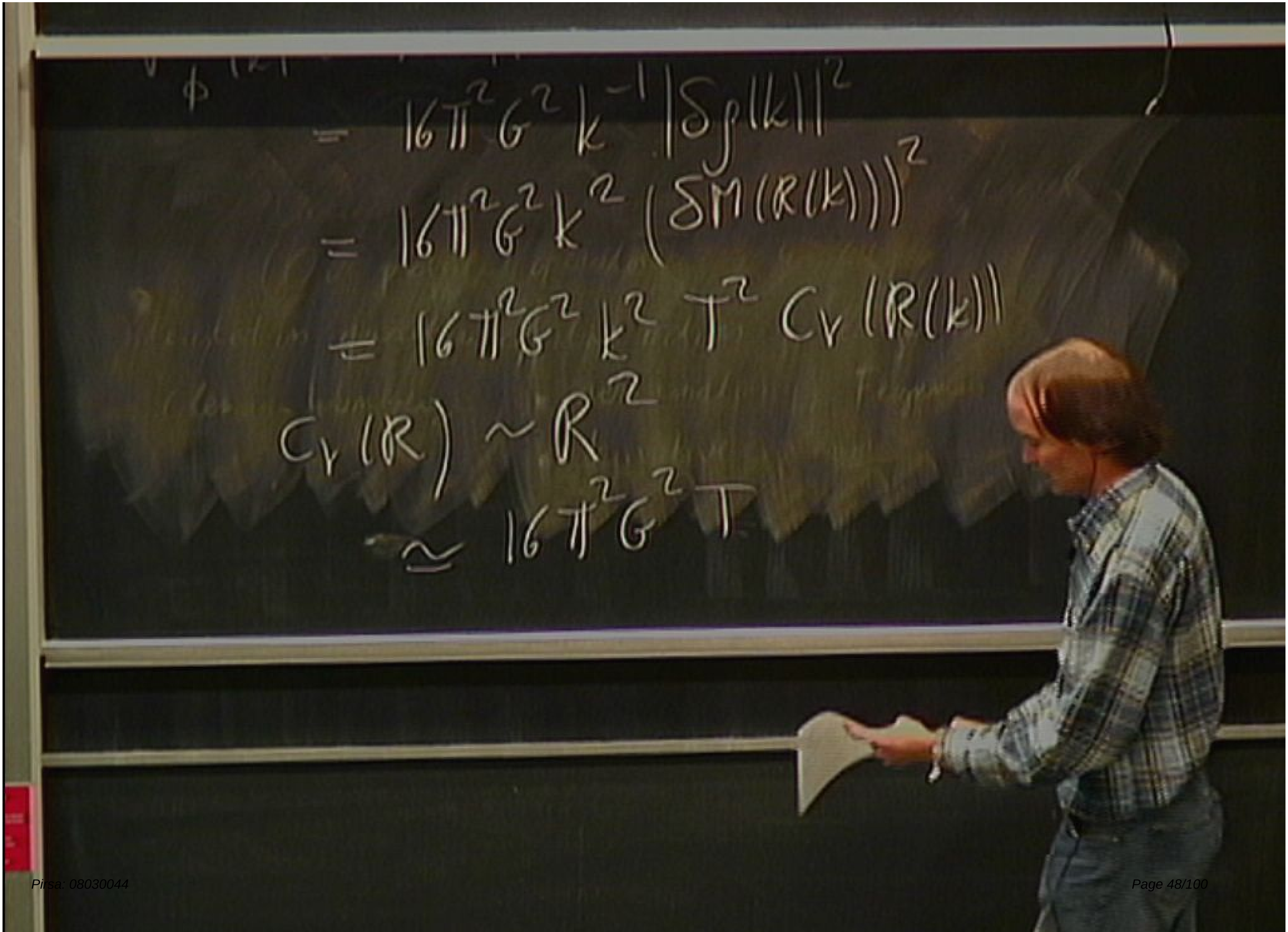
$$D = \phi - \psi$$

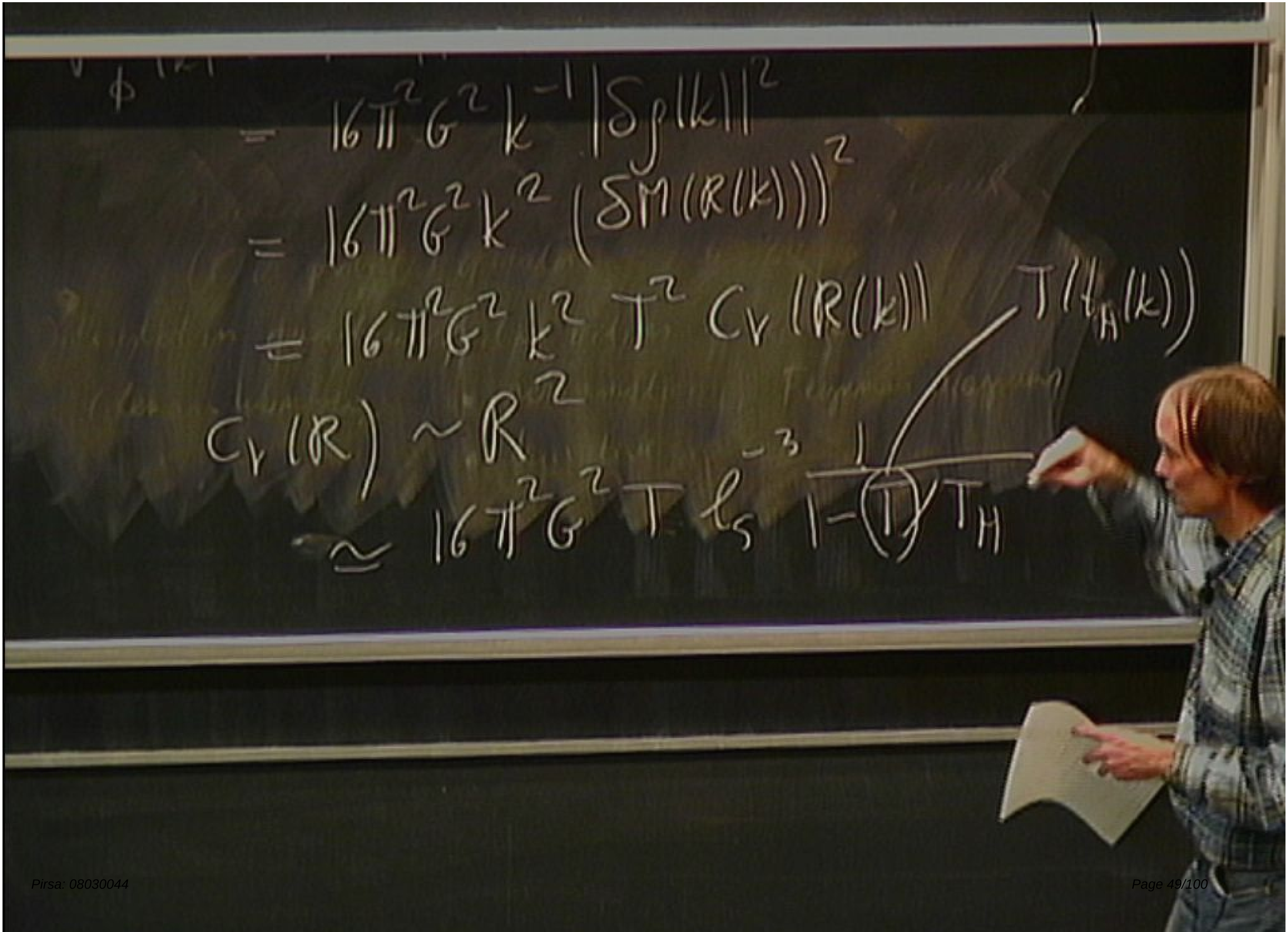

$P_\phi(k) = k^3 |\phi(k)|^2$

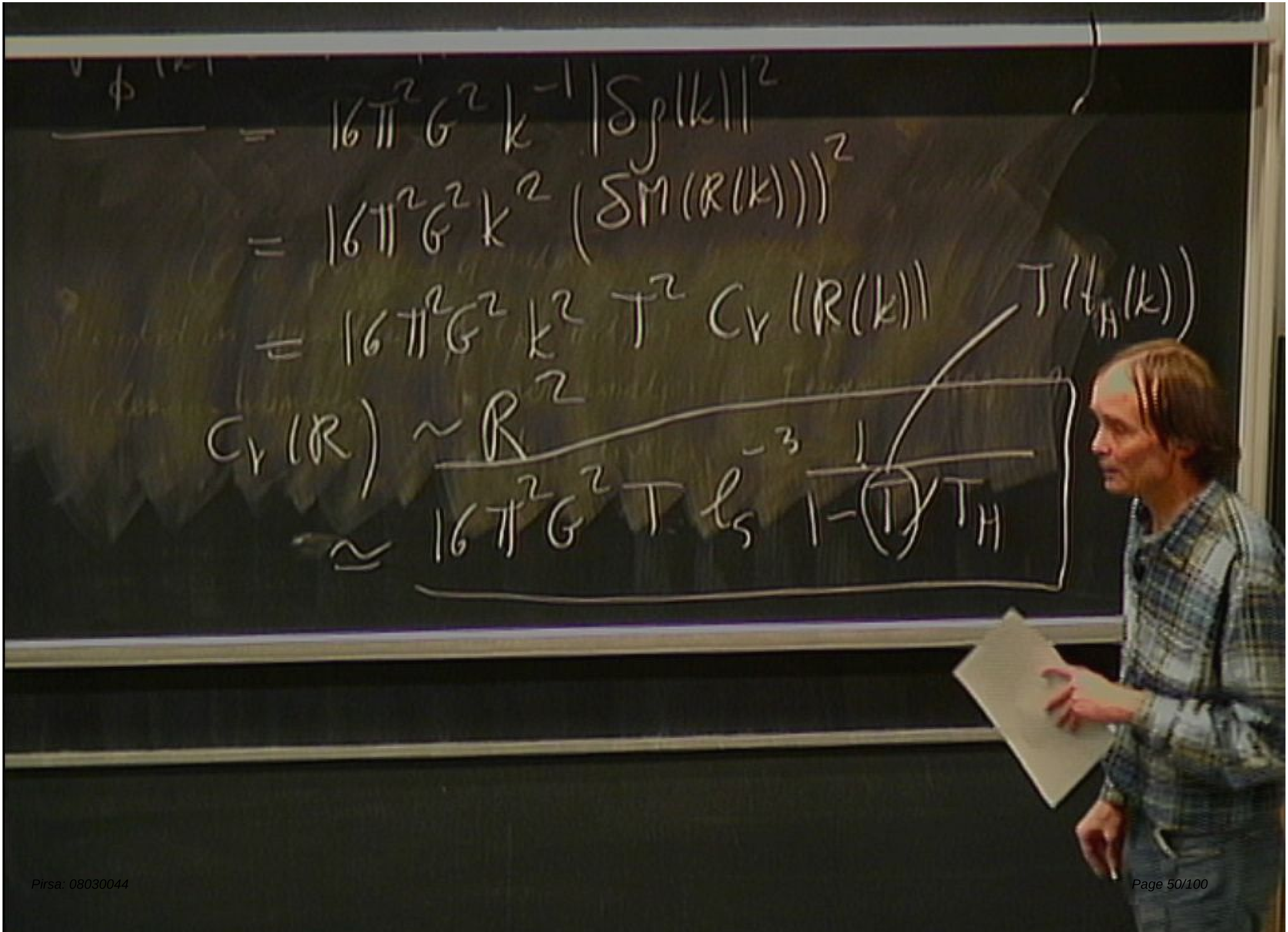

$P_\phi(k) = k^3 |\phi(k)|^2$
$= 16\pi^2 G^2 k^{-1} |\delta\rho(k)|^2$
$= 16\pi^2 G^2 k^2 (\delta M(R(k)))^2$

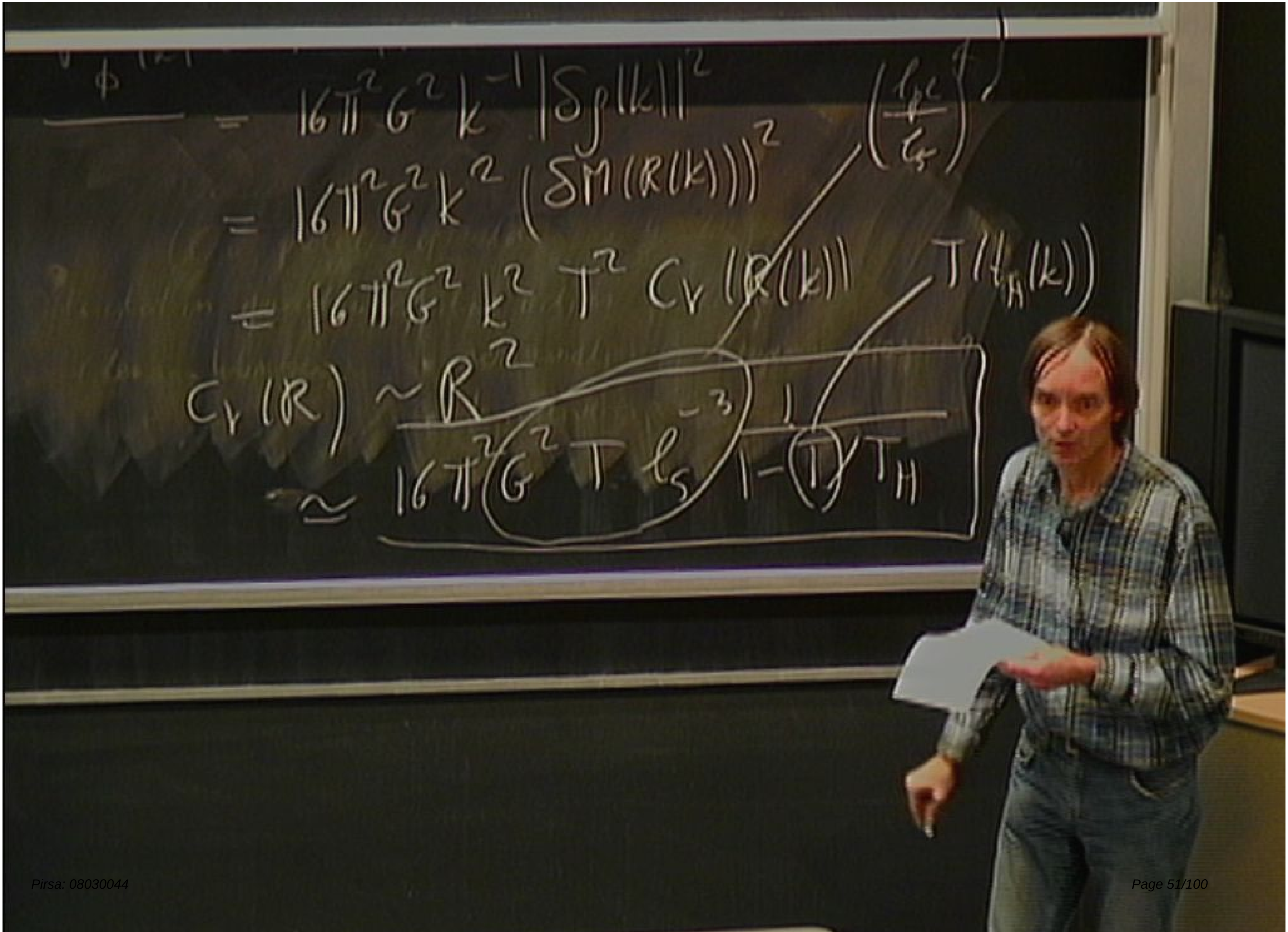


$= 16\pi^2 G^2 k^{-1} |\delta\rho(k)|^2$
$= 16\pi^2 G^2 k^2 (\delta M(R(k)))^2$
$= 16\pi^2 G^2 k^2 T^2 C_V(R(k))$


$= 16\pi^2 G^2 k^{-1} |\delta\rho(k)|^2$
$= 16\pi^2 G^2 k^2 (\delta M(R(k)))^2$
$= 16\pi^2 G^2 k^2 T^2 C_V(R(k))$
$C_V(R) \sim R^2$
$\simeq 16\pi^2 G^2 T$


= 16π² G² k⁻¹ |δρ(k)|²
= 16π² G² k² (δM(R(k)))²
= 16π² G² k² T² C_V(R(k))
T(t_H(k))
C_V(R) ~ R²
≃ 16π² G² T l_s⁻³ 1/(1 − T/T_H)


= 16π² G² k⁻¹ |δρ(k)|²
= 16π² G² k² (δM(R(k)))²
= 16π² G² k² T² C_V(R(k)) T(t_H(k))
C_V(R) ~ R²
≃ 16π² G² T l_s⁻³ 1/(1 − T/T_H)


= 16π² G² k⁻¹ |δρ(k)|²
= 16π² G² k² (δM(R(k)))²
= 16π² G² k² T² C_V(R(k))
C_V(R) ~ R²
~ 16π² G² T l_s⁻³ 1/(1 − T/T_H)
T(t_H(k))

$$= 16\pi^2 G^2 k^{-1} |\delta\rho(k)|^2$$

$$= 16\pi^2 G^2 k^2 \left(\delta M(R(k))\right)^2$$

$$= 16\pi^2 G^2 k^2 T^2 C_V(R(k))$$

$$\left(\frac{\ell_{pl}}{\ell_s}\right)^4 \qquad T(t_H(k))$$

$$C_V(R) \sim R^2$$

$$\boxed{\simeq 16\pi^2 G^2 T \ell_s^{-3} \frac{1}{1 - T/T_H}}$$

$$= 16\pi^2 G^2 k^{-1} |\delta\rho(k)|^2$$

$$\left(\frac{l_{pl}}{l_s}\right)^4 \sim 10^{-12}$$

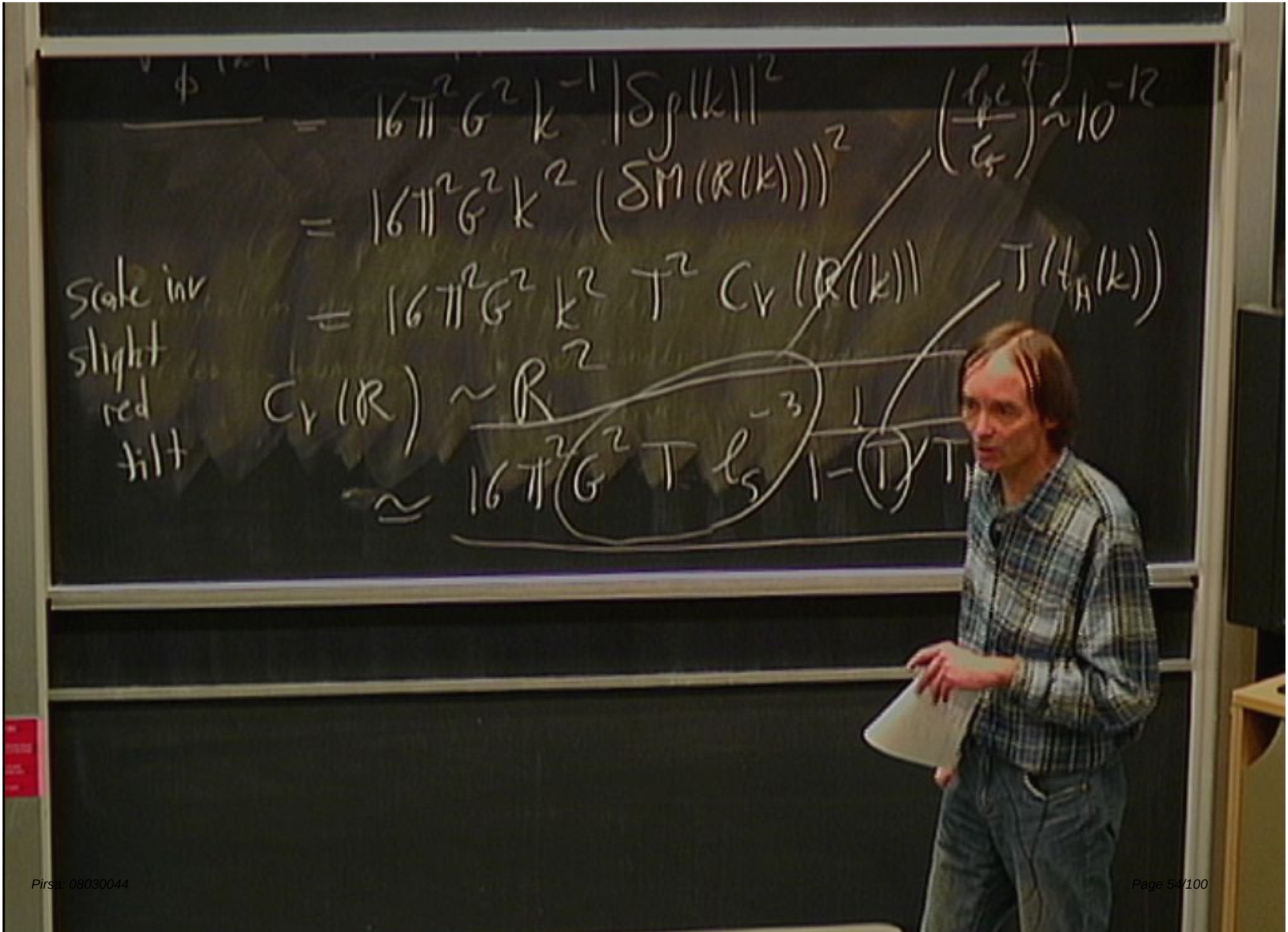
$$= 16\pi^2 G^2 k^2 (\delta M(R(k)))^2$$

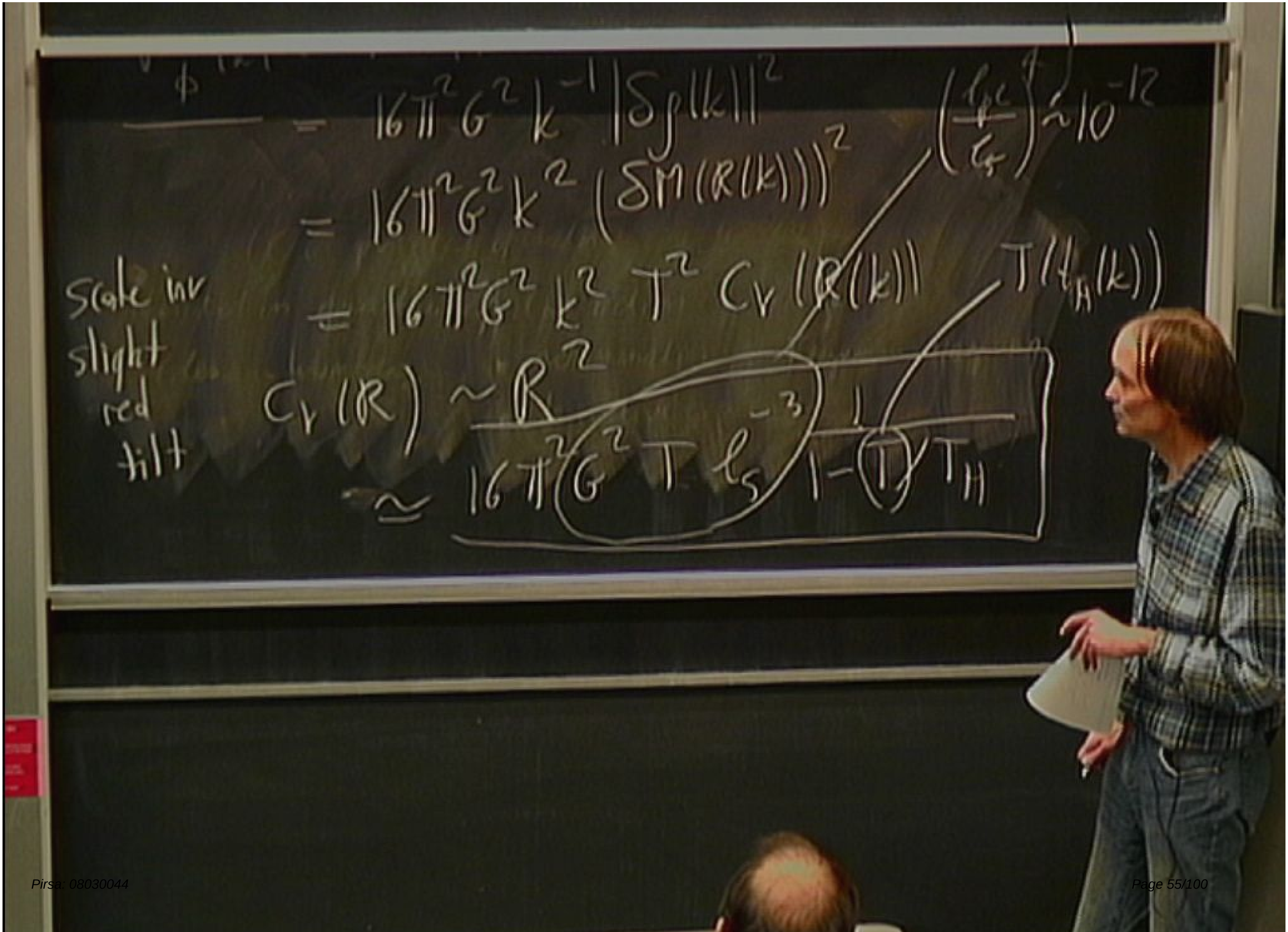
$$= 16\pi^2 G^2 k^2 T^2 C_V(R(k))$$

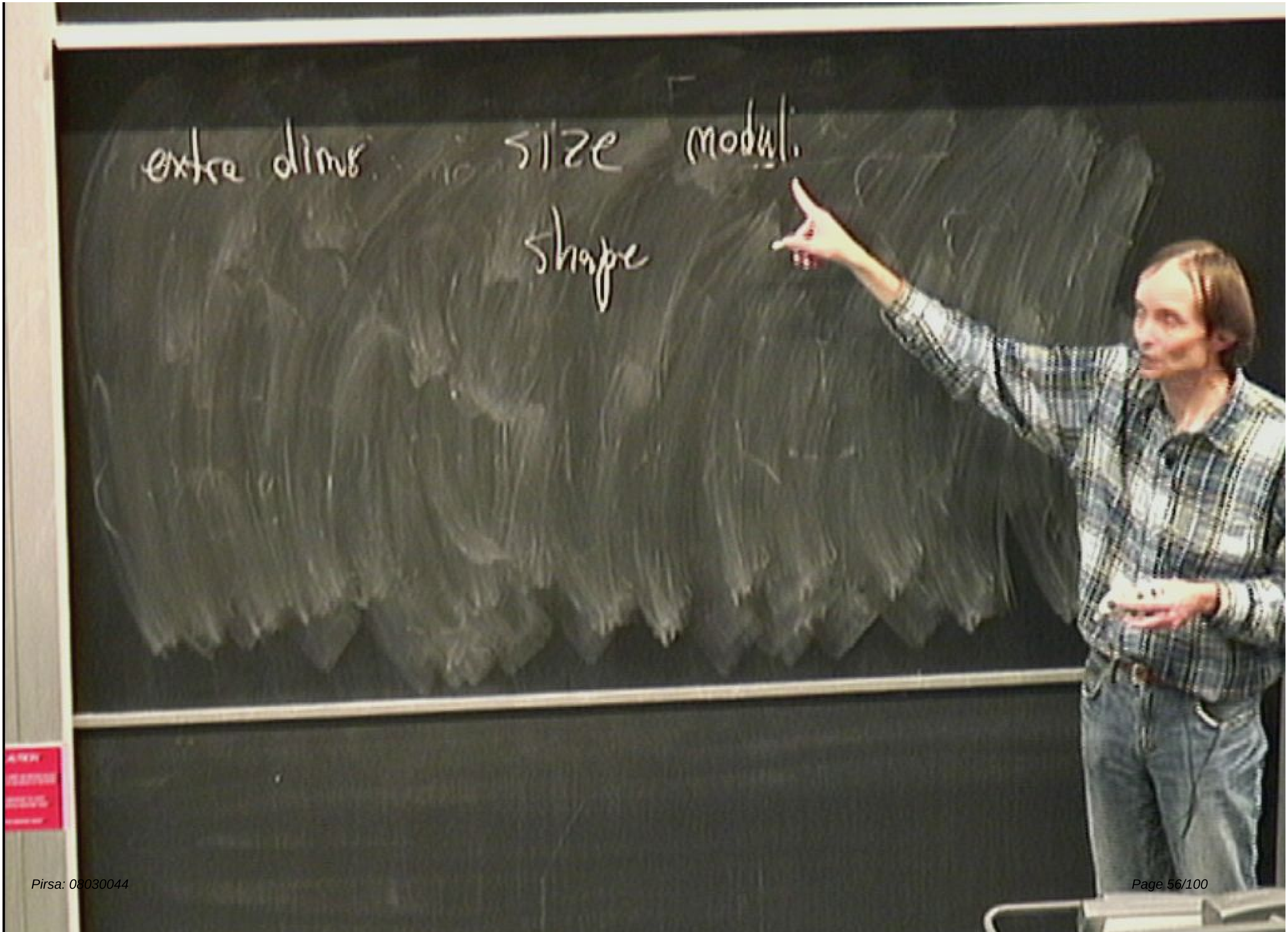
$$T(t_H(k))$$

$$C_V(R) \sim R^2$$

$$\simeq 16\pi^2 G^2 T l_s^{-3} \frac{1}{1 - T/T_H}$$


= 16π² G² k⁻¹ |δρ(k)|²
(l_pc / l_s)⁴ ~ 10⁻¹²
= 16π² G² k² (δM(R(k)))²
scale inv
slight
red
tilt
= 16π² G² k² T² C_V(R(k))
T(t_H(k))
C_V(R) ~ R²
≃ 16π² G² T l_s⁻³
1
1 − (T/T_H)


$= 16\pi^2 G^2 k^{-1} |\delta\rho(k)|^2$
$\left(\frac{\ell_{pc}}{\ell_s}\right)^4 \sim 10^{-12}$
$= 16\pi^2 G^2 k^2 (\delta M(R(k)))^2$
scale inv
slight
red
tilt
$= 16\pi^2 G^2 k^2 T^2 C_V(R(k))$
$T(t_H(k))$
$C_V(R) \sim R^2$
$\simeq 16\pi^2 G^2 T \ell_s^{-3} \frac{1}{1 - T/T_H}$


extra dims
size
moduli
shape

extra dims : size moduli

shape "

dilaton

extra fields

extra dims: size moduli

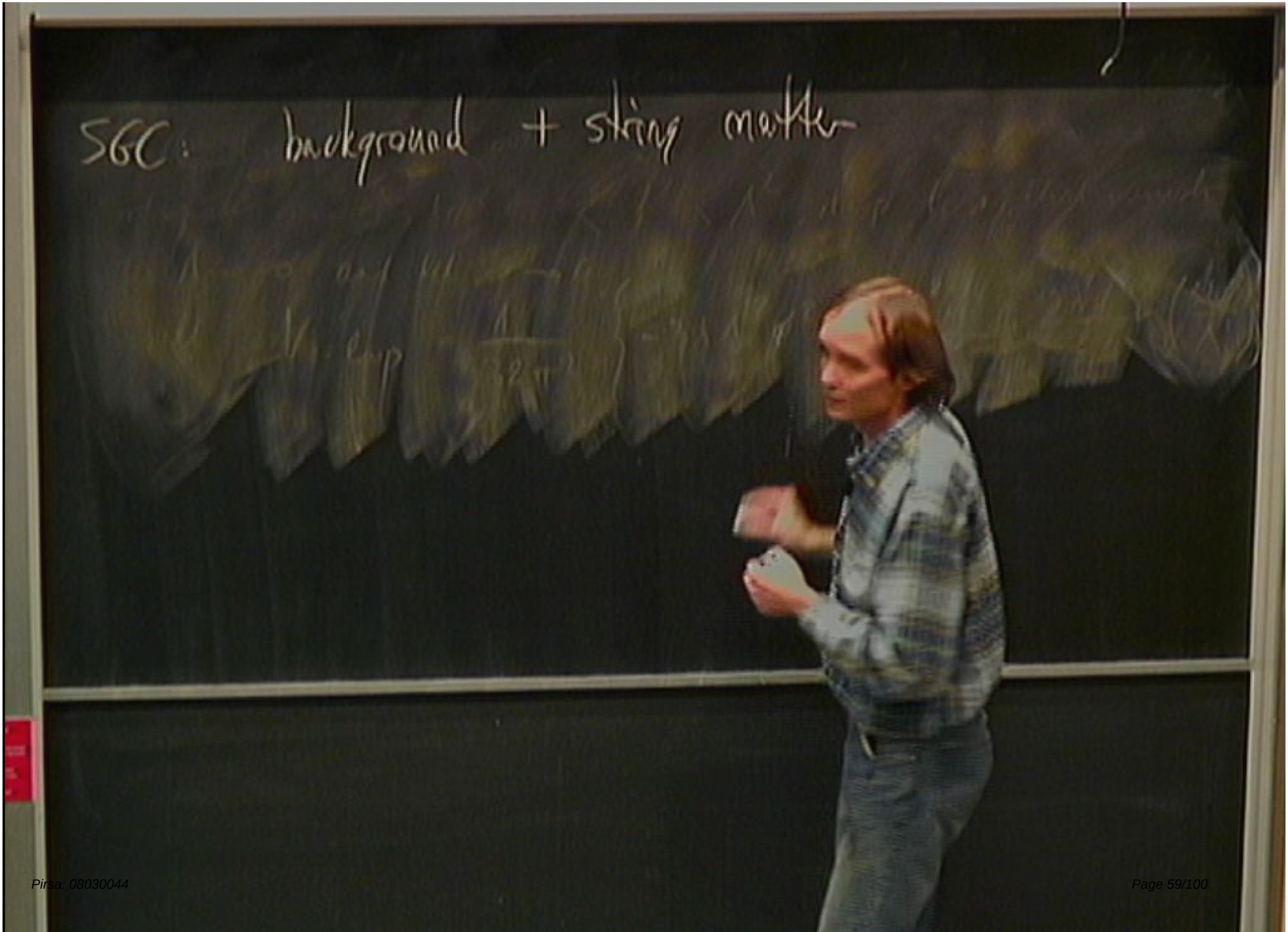
shape "

dilaton

extra fields

usual approach: fluxes ⟶ shape stabiliz.

gaugino condens. ⟶ size & dilaton stabilization

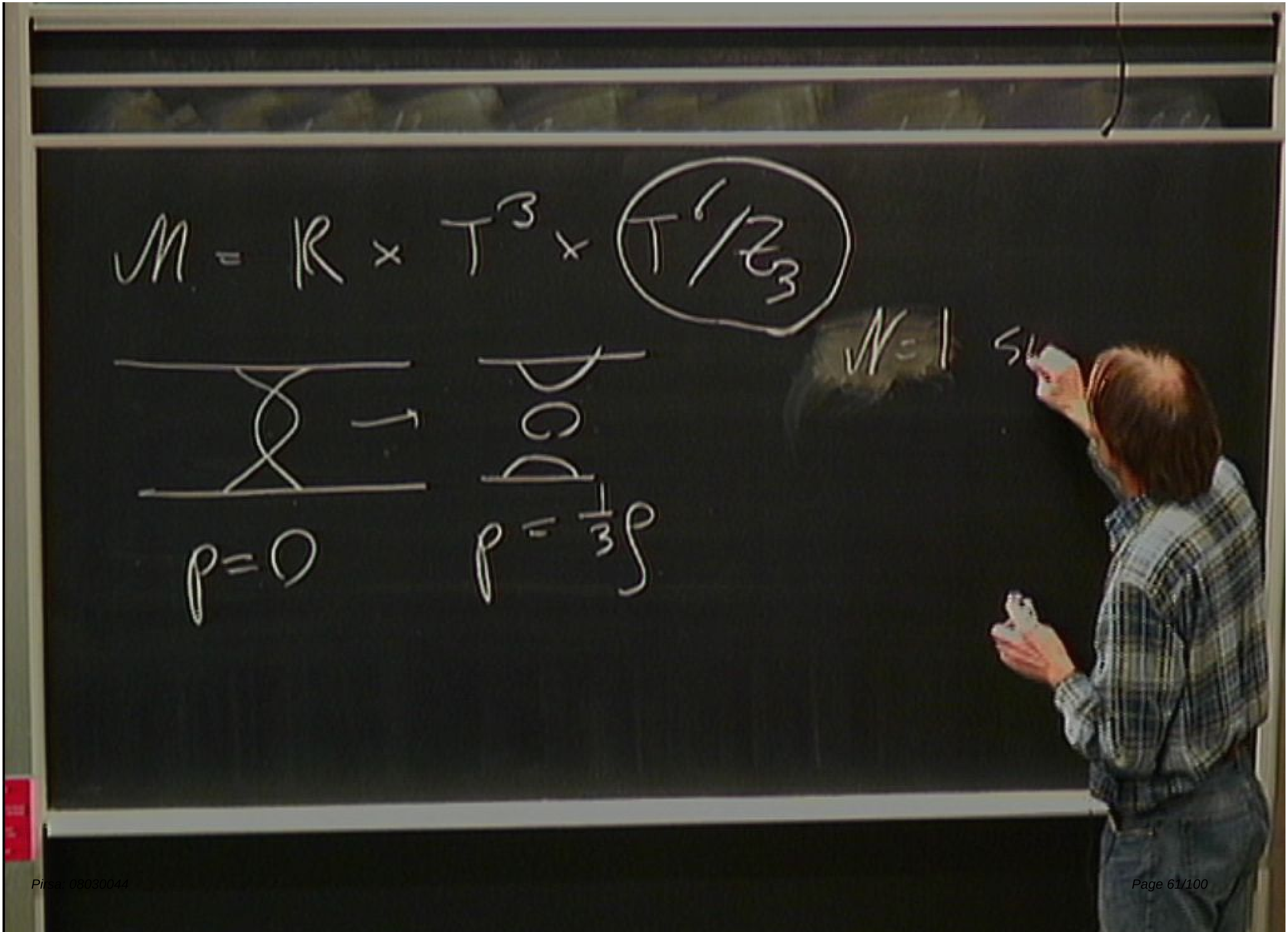

SGC: background + string matter

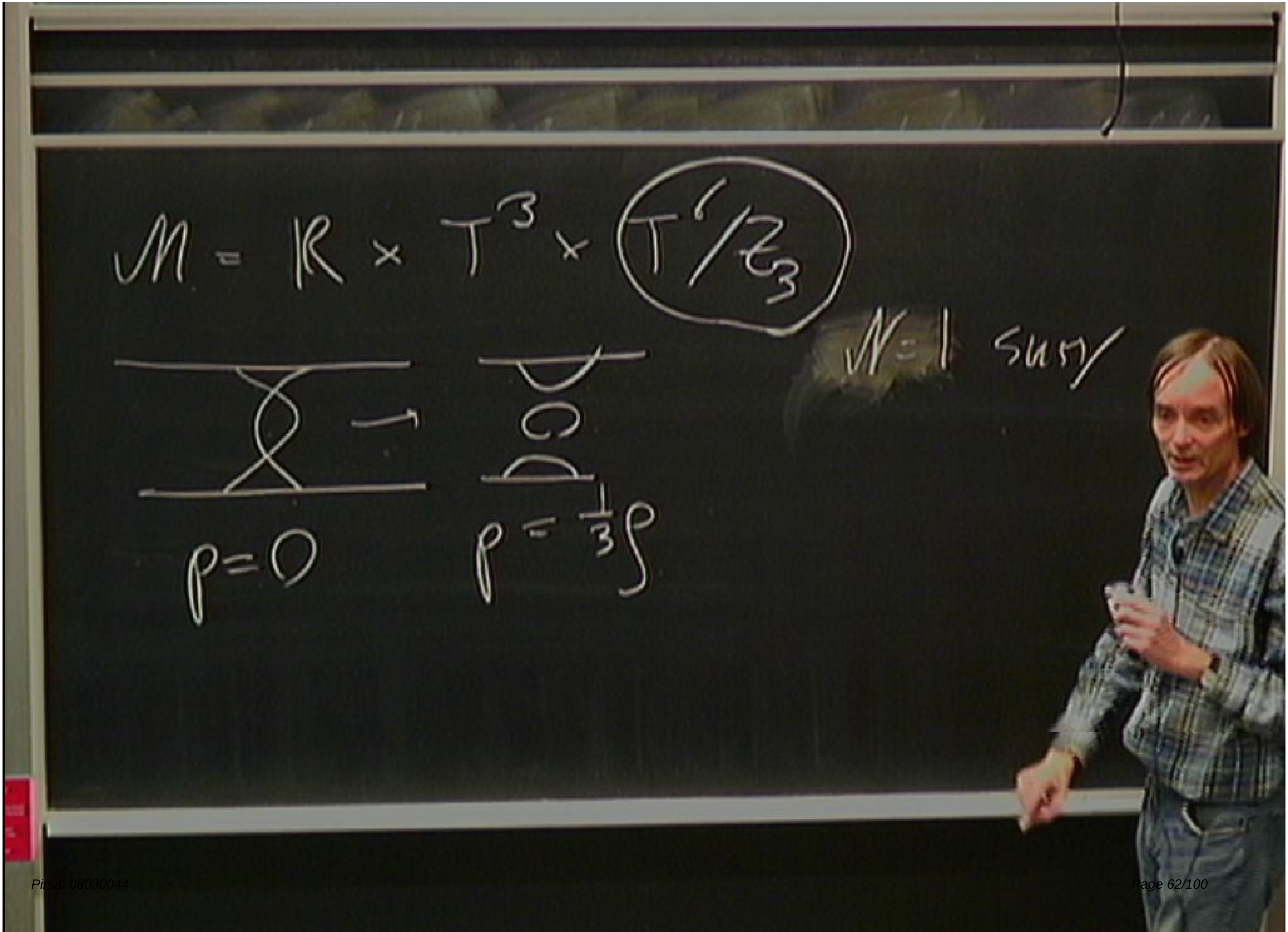
SGC: background + string matter

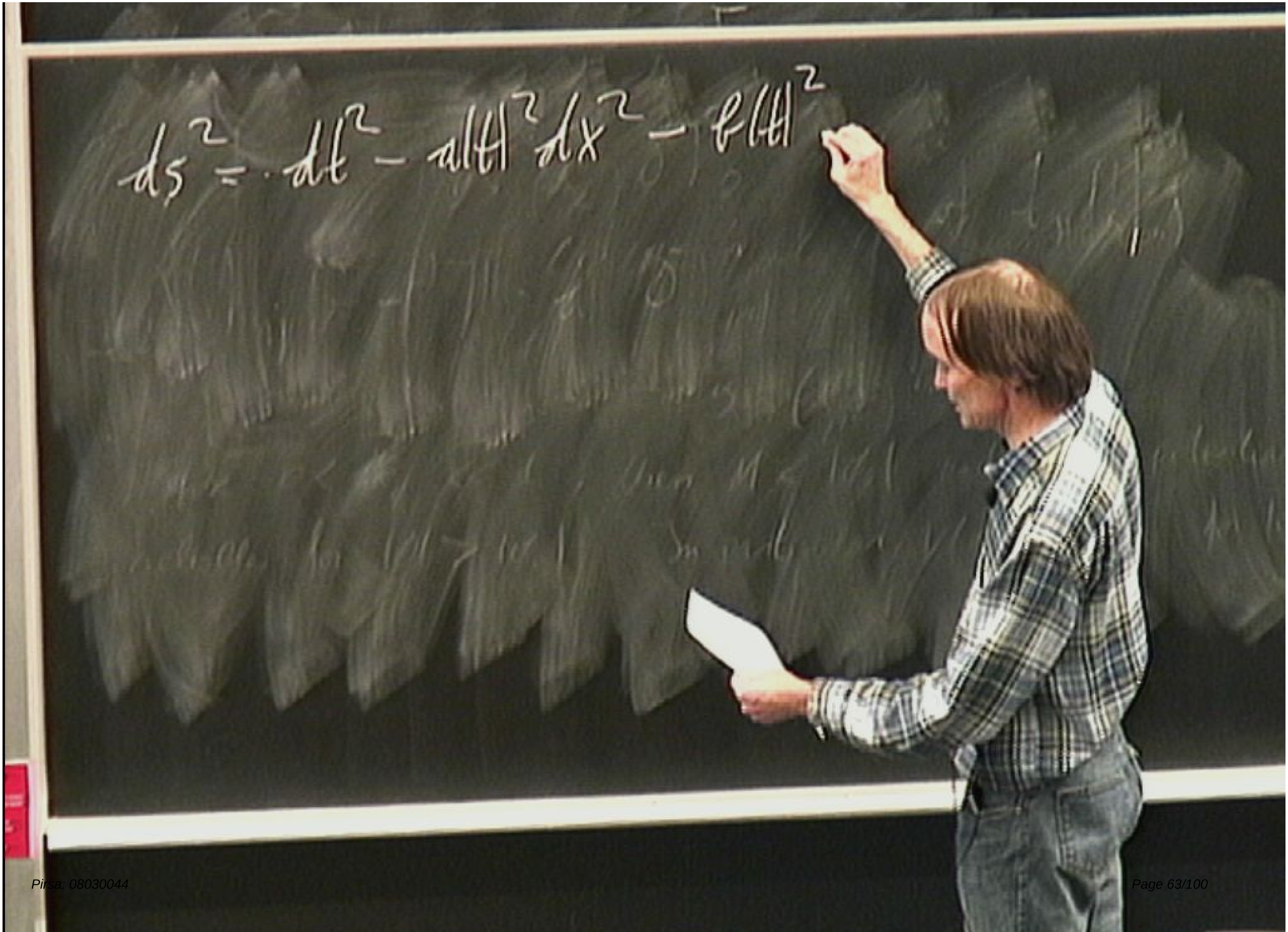
↓

stabilizes shape & size moduli

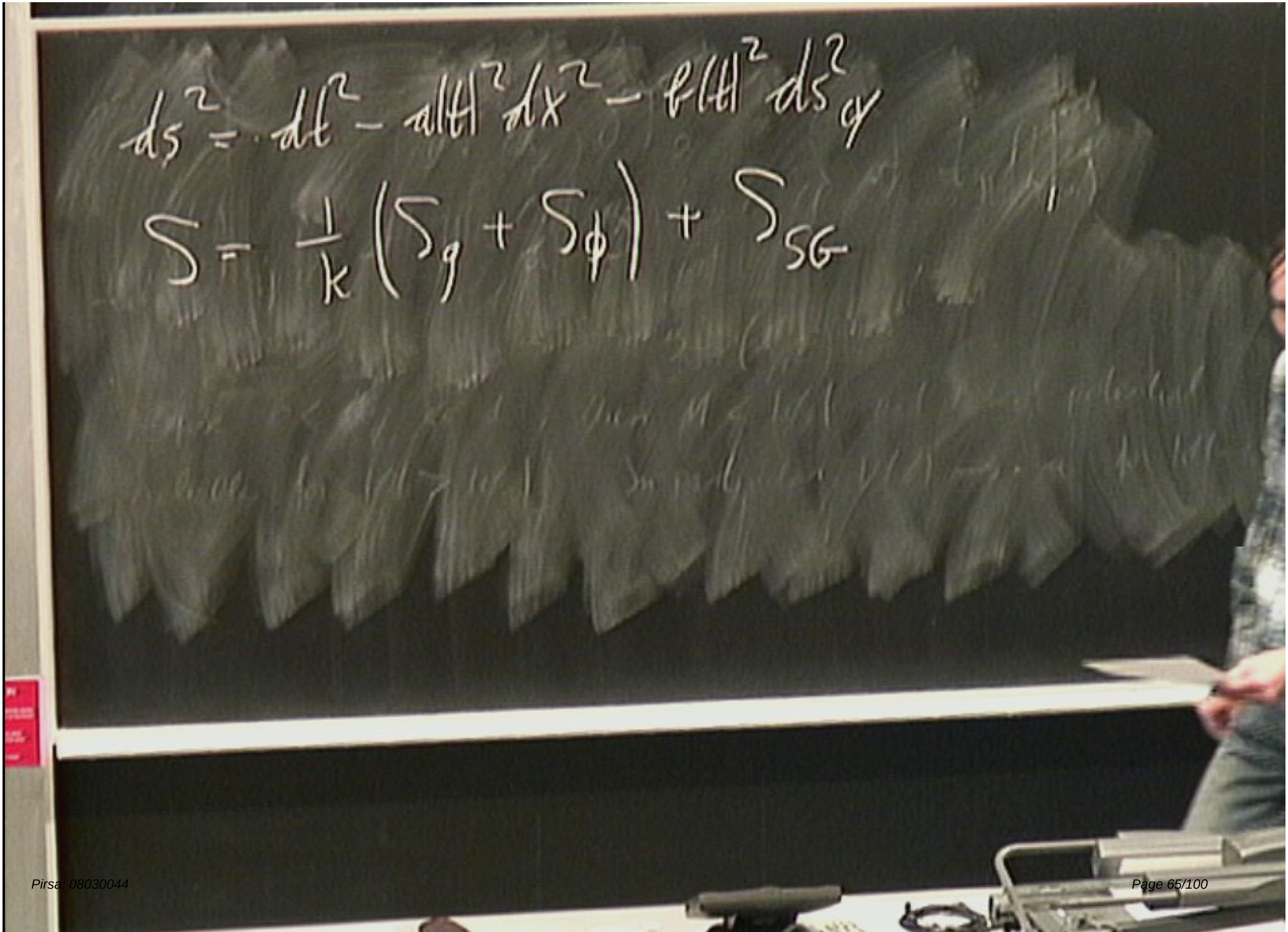
gaugino condens. ⟶ dilaton stabiliz.


$\mathcal{M} = \mathbb{R} \times T^3 \times T^6/\mathbb{Z}_3$
$\mathcal{N}=1$
$\rho=0$
$\rho = \frac{1}{3}\rho$


$\mathcal{M} = \mathbb{R} \times T^3 \times T^1/\mathbb{Z}_3$
$\mathcal{N}=1$ susy
$\rho = 0$
$\rho = \frac{1}{3}\rho$


$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2$

$$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 ds_{\mathcal{Y}}^2$$


$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 ds_Y^2$
$S = -\frac{1}{k}(S_g + S_\phi) + S_{SG}$

$$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 ds_Y^2$$

$$S = -\frac{1}{k}\left(S_g + S_\phi\right) + S_{SG}$$

$$S_{SG} = \int d^{10}x \sqrt{-g} \sum_\alpha \mu_\alpha \varepsilon_\alpha$$

ε_α: energy of string state

μ_α: # density

$$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 ds^2_{cy}$$

$$S = -\frac{1}{k}\left(S_g + S_\phi\right) + S_{SG}$$

$$S_{SG} = \int d^{10}x \sqrt{-g} \sum_\alpha \mu_\alpha \, \varepsilon_\alpha$$

energy of string state

density

$$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 ds_q^2$$

$$S = -\frac{1}{k}\left(S_g + S_\phi\right) + S_{SG}$$

$$S_{SG} = \int d^{10}x \sqrt{-g} \sum_\alpha \mu_\alpha \varepsilon_\alpha$$

density

energy of string st

Variational eqs.

$\rightarrow$ EOM for ϕ & $b(t)$

$$ds^2 = dt^2 - a(t)^2 dx^2 - b(t)^2 ds_y^2$$

$$S = -\frac{1}{k}\left(S_g + S_\phi\right) + S_{SG}$$

$$S_{SG} = \int d^{10}x \sqrt{-g} \sum_\alpha \mu_\alpha \, \varepsilon_\alpha$$

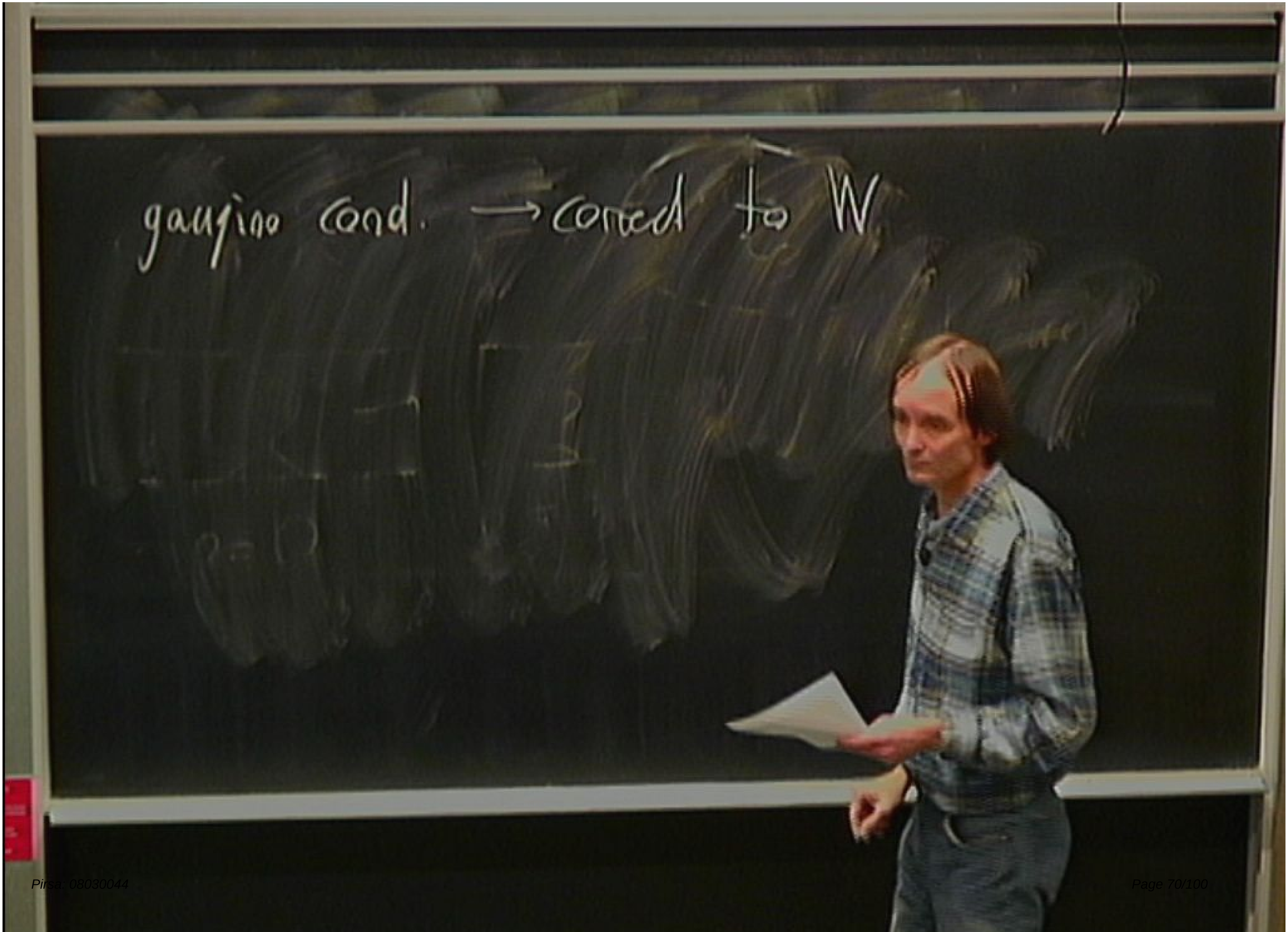
duality ← energy of string state

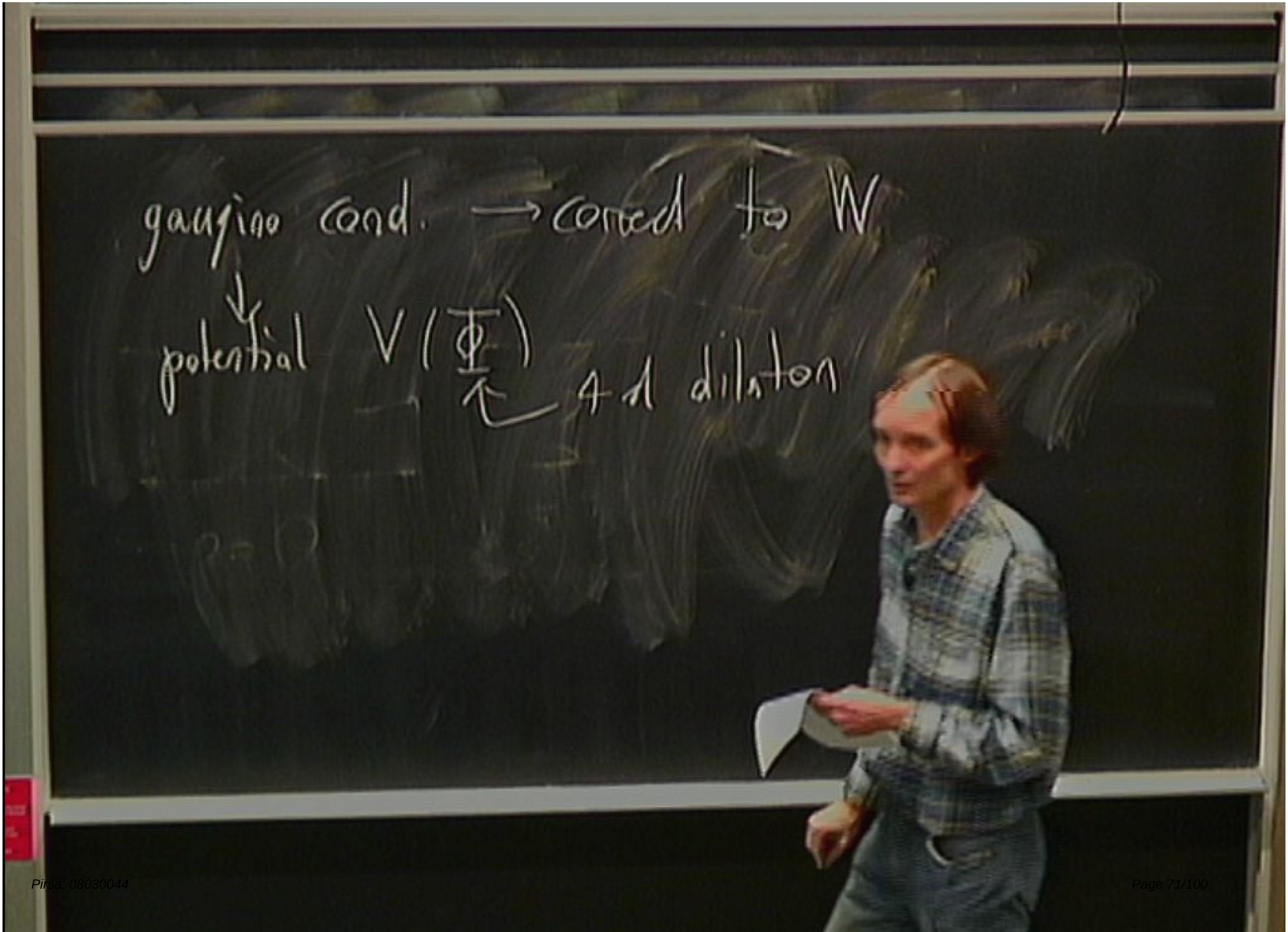
variational eqs.

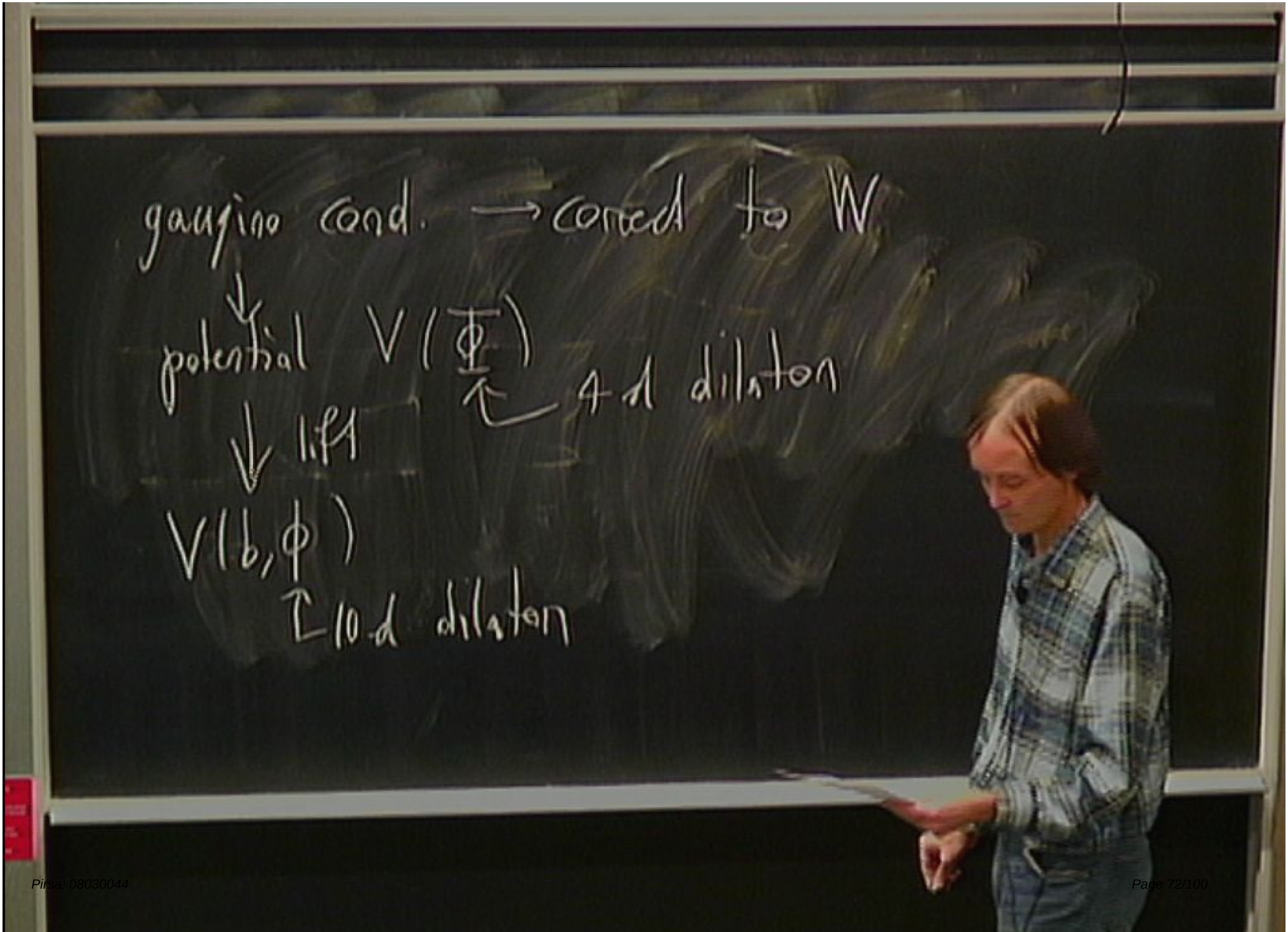
→ EOM for ϕ & $b(t)$

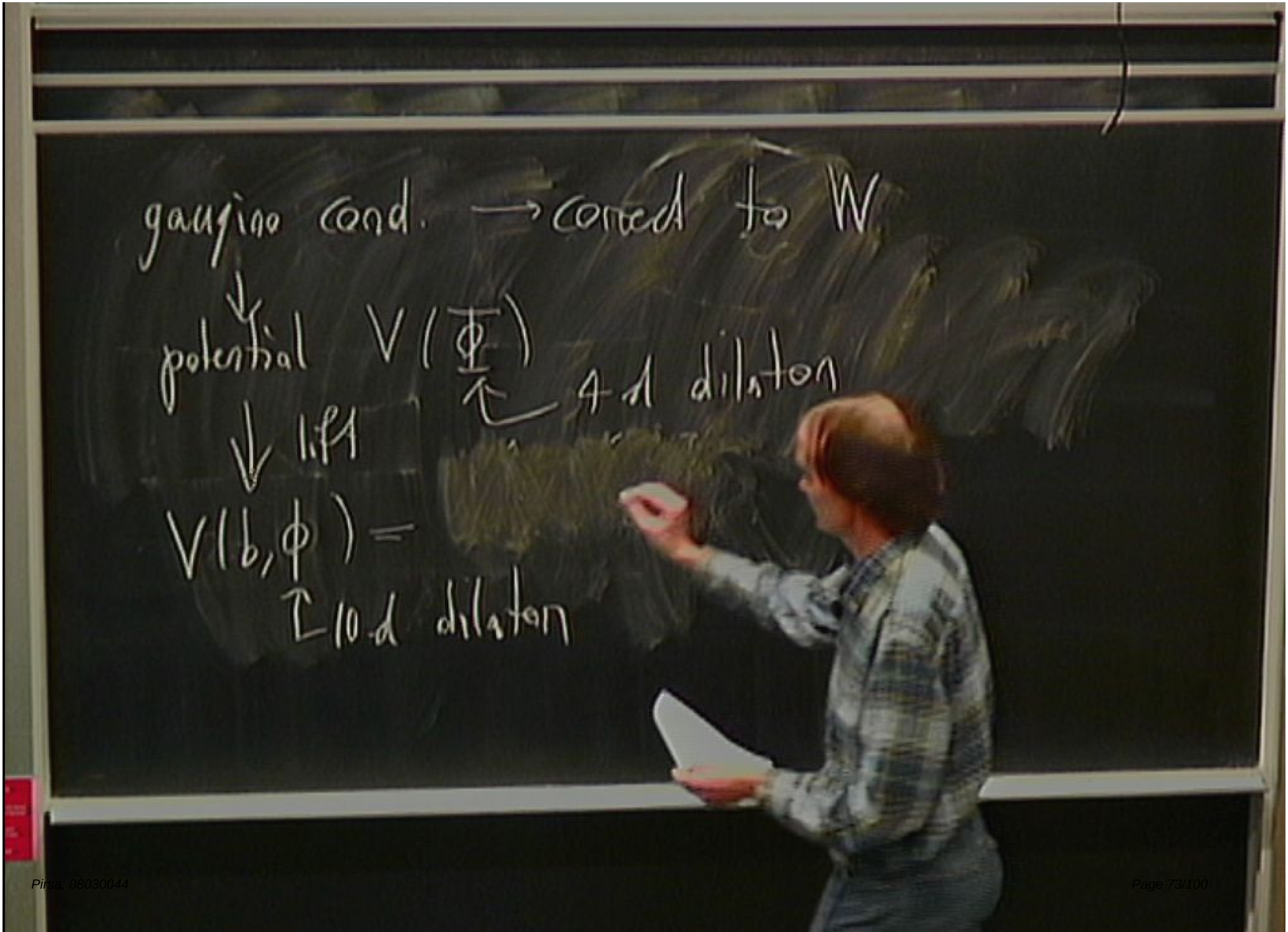
shape //

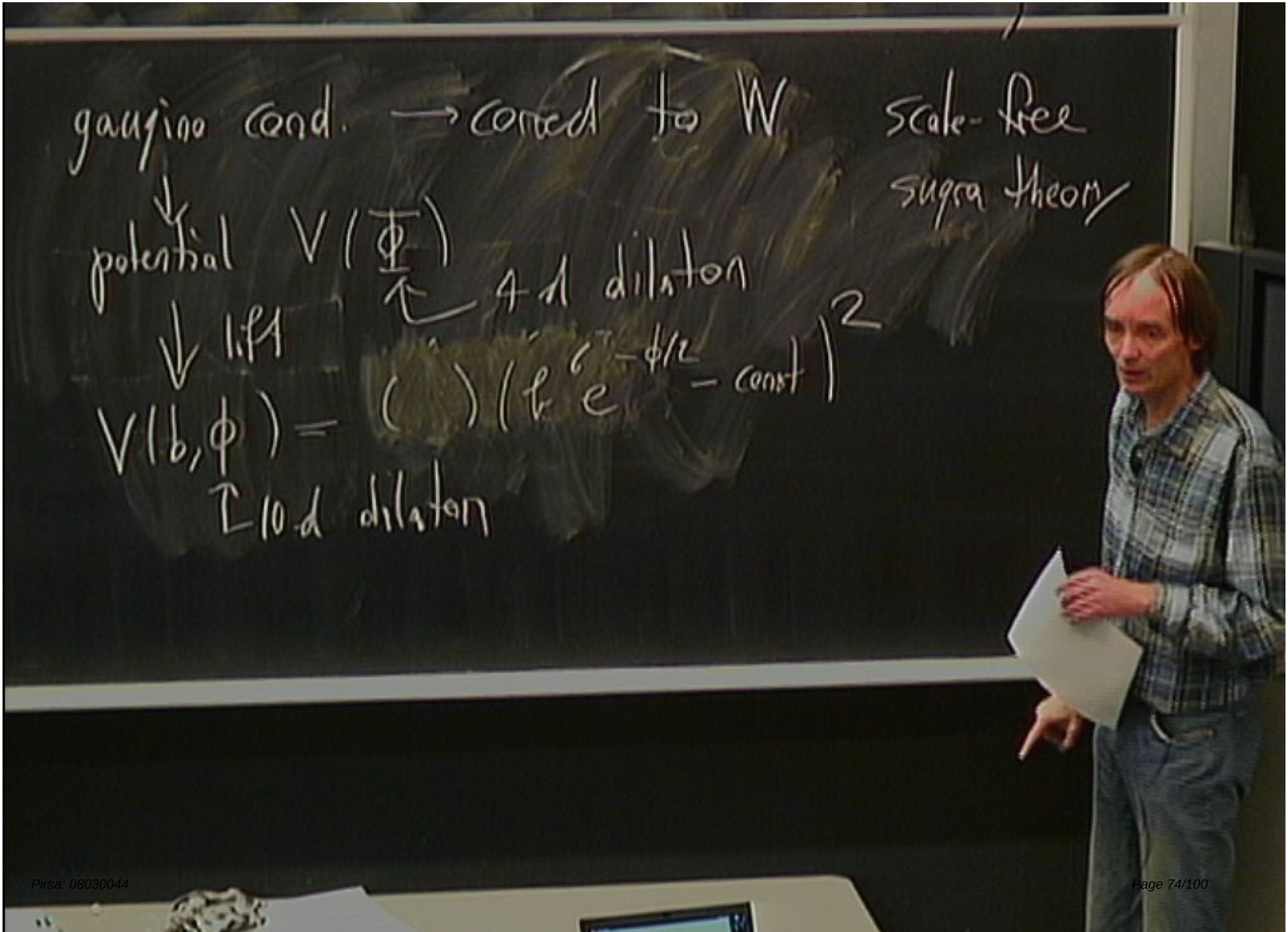
dilaton

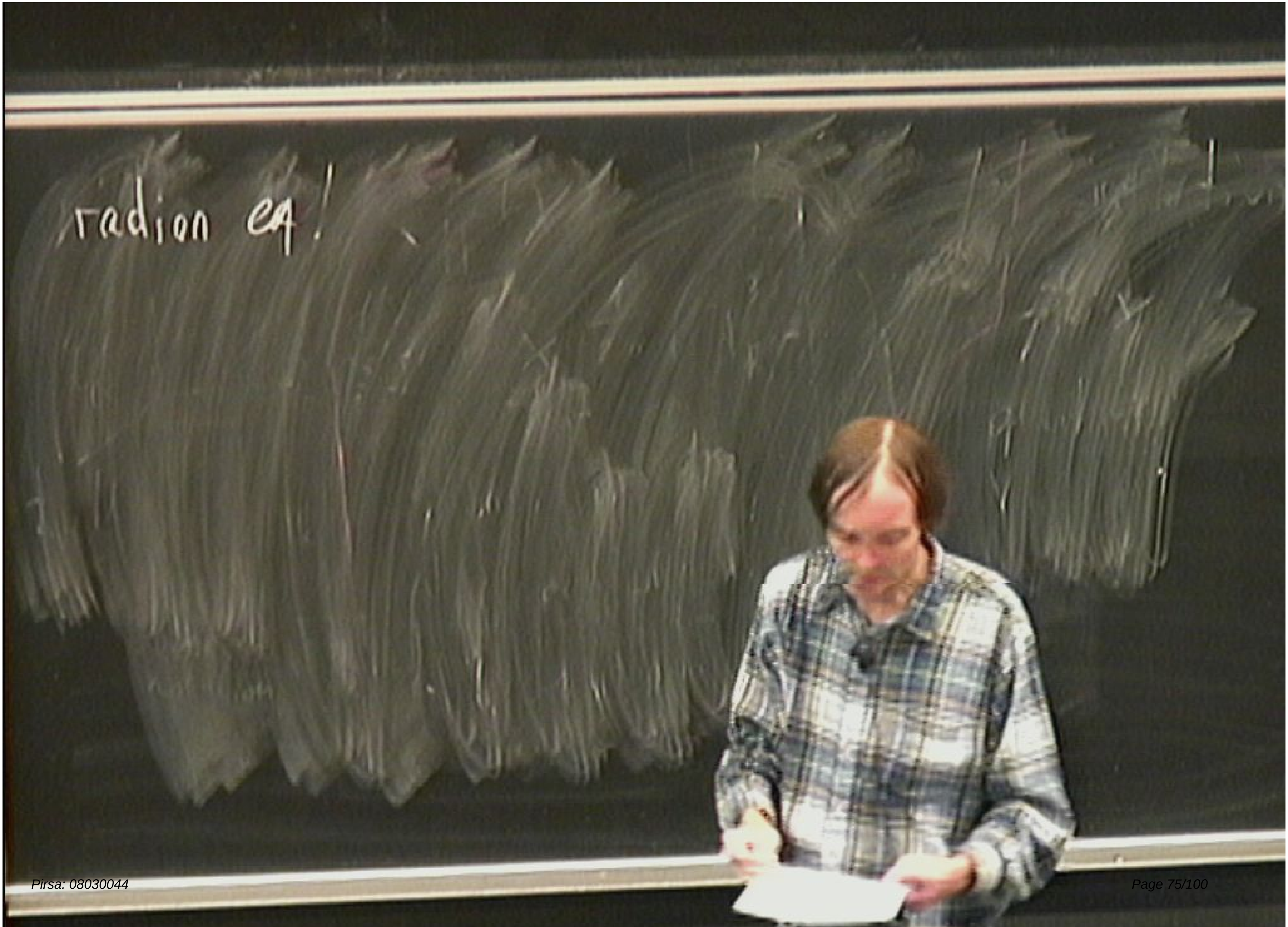

gaugino cond. → correct to W

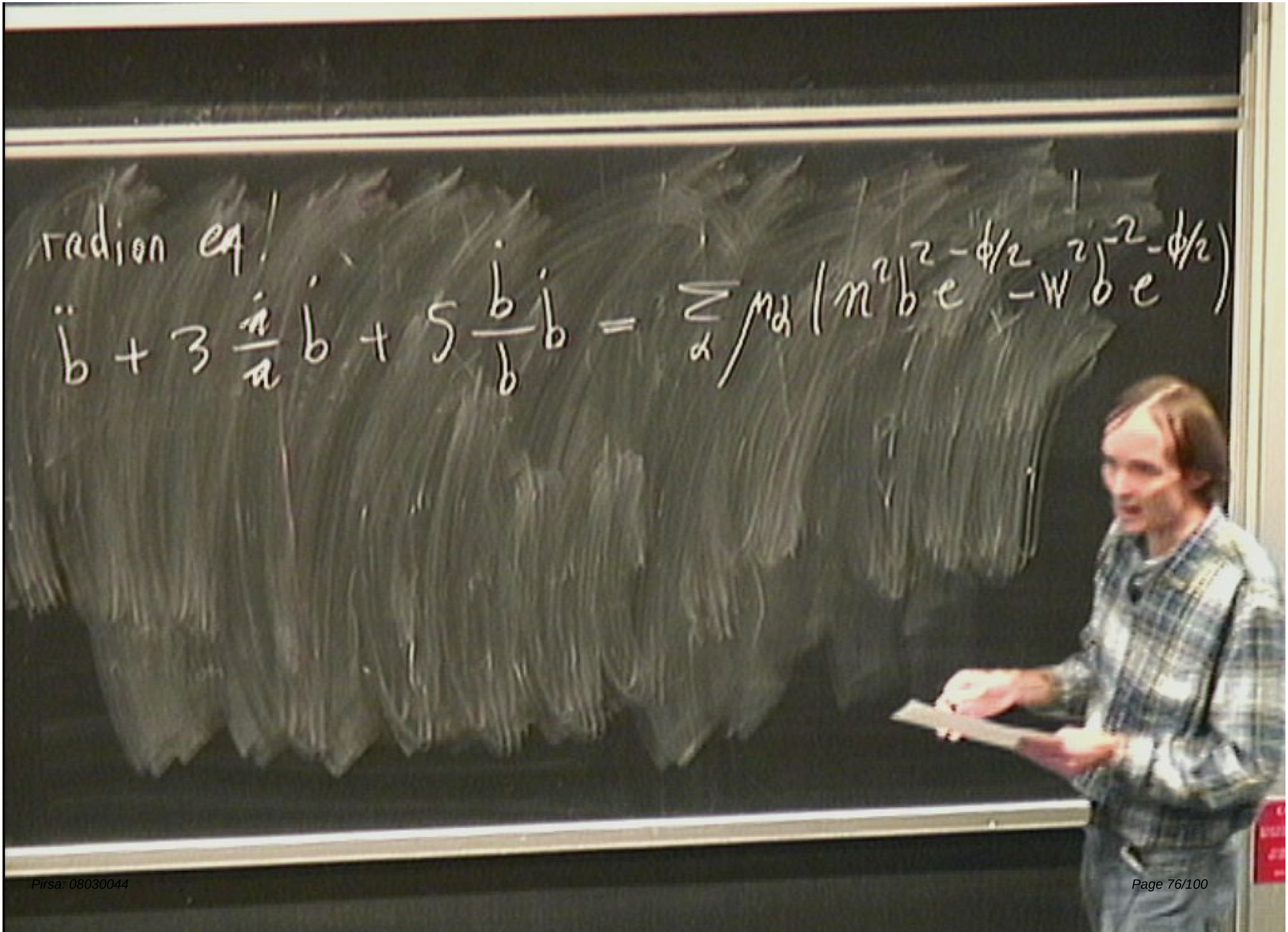

gaugino cond. → correct to W
potential V(Φ)
4d dilaton


gaugino cond. → correct to W
↓
potential V(Φ) ← 4 d dilaton
↓ lift
V(b, φ)
↑ 10 d dilaton


gaugino cond. → correct to W
↓
potential V(Φ)
4 d dilaton
↓ lift
V(b, φ) =
10 d dilaton


gaugino cond. → coupled to W
scale-free sugra theory
potential V(Φ)
4d dilaton
lift
V(b, φ) = ( )(b e^{-φ/2} - const)^2
10 d dilaton

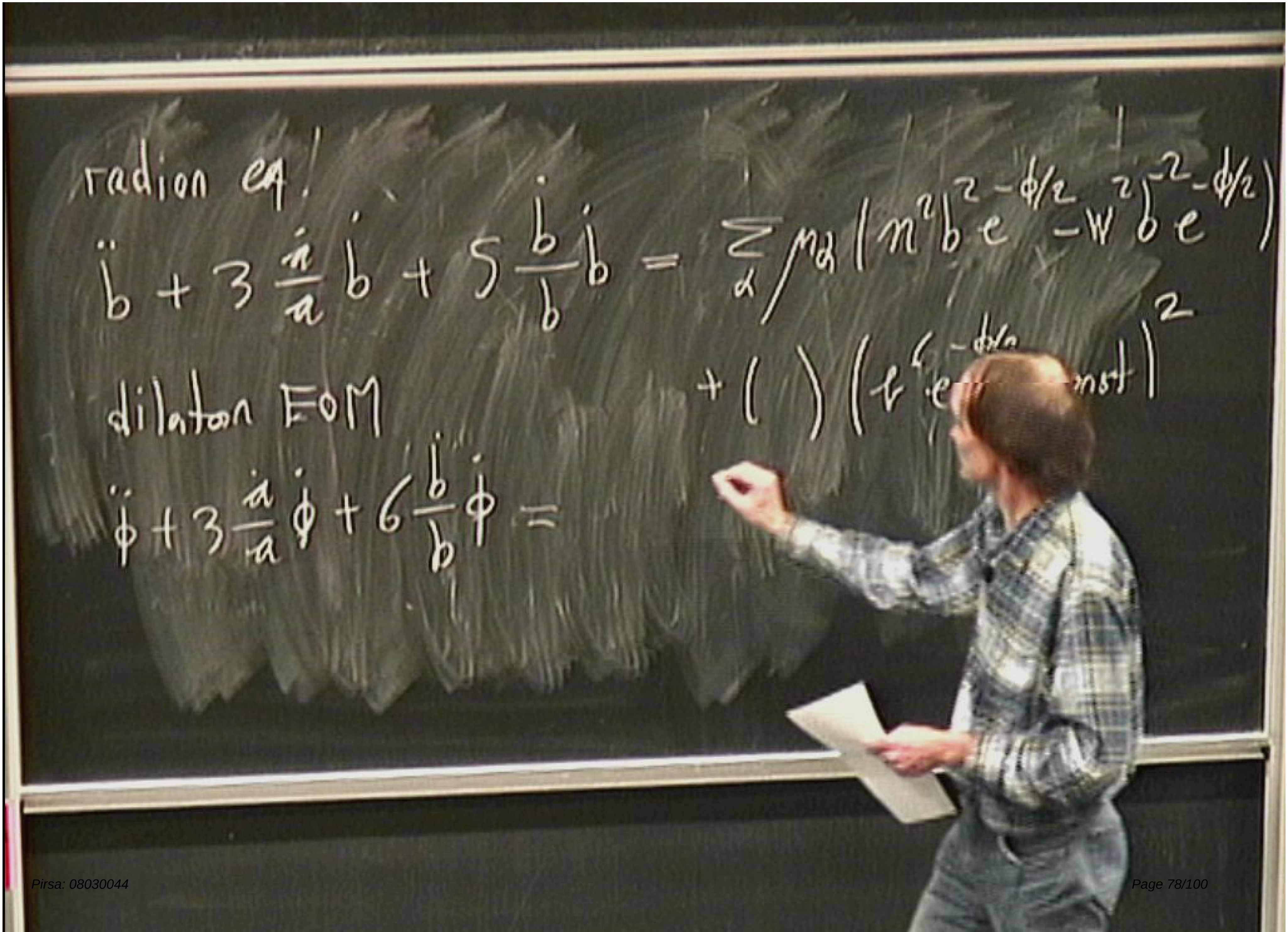

radion eq!


radion eq:
$\ddot{b} + 3\frac{\dot{a}}{a}\dot{b} + 5\frac{\dot{b}}{b}\dot{b} = \sum_\alpha \mu_\alpha \left(n^2 b^{-2} e^{-\phi/2} - w^2 b^{2} e^{-\phi/2}\right)$

radion eq:

$$\ddot{b} + 3\frac{\dot{a}}{a}\dot{b} + 5\frac{\dot{b}}{b}\dot{b} = \sum_\alpha \mu_\alpha \left(n^2 b^{2} e^{-\phi/2} - w^2 b^{-2} e^{-\phi/2} \right)$$

$$+ (\quad)\left(b^4 e^{-\phi/2} - \text{const} \right)^2$$


radion eq:
$\ddot{b} + 3\frac{\dot{a}}{a}\dot{b} + 5\frac{\dot{b}}{b}\dot{b} = \sum_\alpha \mu_\alpha \left(n^2 b^{2} e^{-\phi/2} - w^2 b^{-2} e^{-\phi/2} \right)$
$+ (\ )\left(b^6 e^{-\phi/2} - \text{const} \right)^2$
dilaton EOM
$\ddot{\phi} + 3\frac{\dot{a}}{a}\dot{\phi} + 6\frac{\dot{b}}{b}\dot{\phi} =$

radion eq.

$$\ddot{b} + 3\frac{\dot{a}}{a}\dot{b} + 5\frac{\dot{b}}{b}\dot{b} = \sum_{\alpha} \mu_{\alpha}\left(n^2 b^{2} e^{-\phi/2} - w^2 b^{-2} e^{-\phi/2}\right)$$

$$+ (\quad)\left(b^6 e^{-\phi/2} - \text{const}\right)^2$$

dilaton EOM

$$\ddot{\phi} + 3\frac{\dot{a}}{a}\dot{\phi} + 6\frac{\dot{b}}{b}\dot{\phi} = \sum_{\alpha} \mu_{\alpha}\left(n^2 b^{2} \ldots - w^2 b^{2} e \quad\right)$$

$$+ (\quad)\left(b^6 e^{-\phi/2} - \text{const}\right)^2$$

$$+ (\quad)\left(b^6 e^{-\phi/2} - \text{const}\right)$$

1. (String Gas Cosmology) (SGC)

2. SGC & Structure Formation

3. Moduli Stabilization in SGC

4. Background for SGC

5. SGC & Flatness Problem

A. Nayeri, R.B. & C.

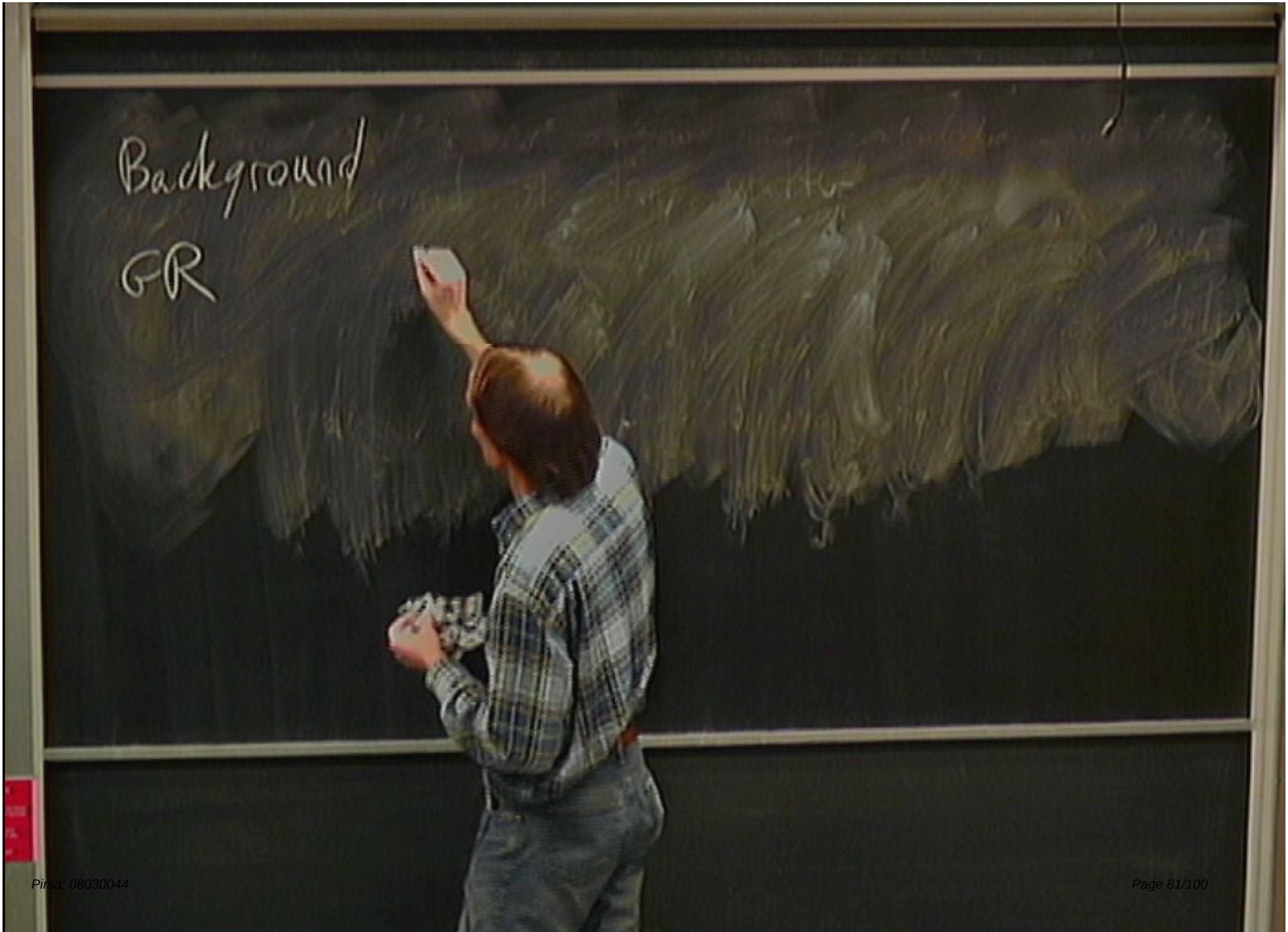
S. Patil & R.B.

E. Cheung et.al

R. Danos, A. Frey & R

R.B., A. Frey & S. Kan

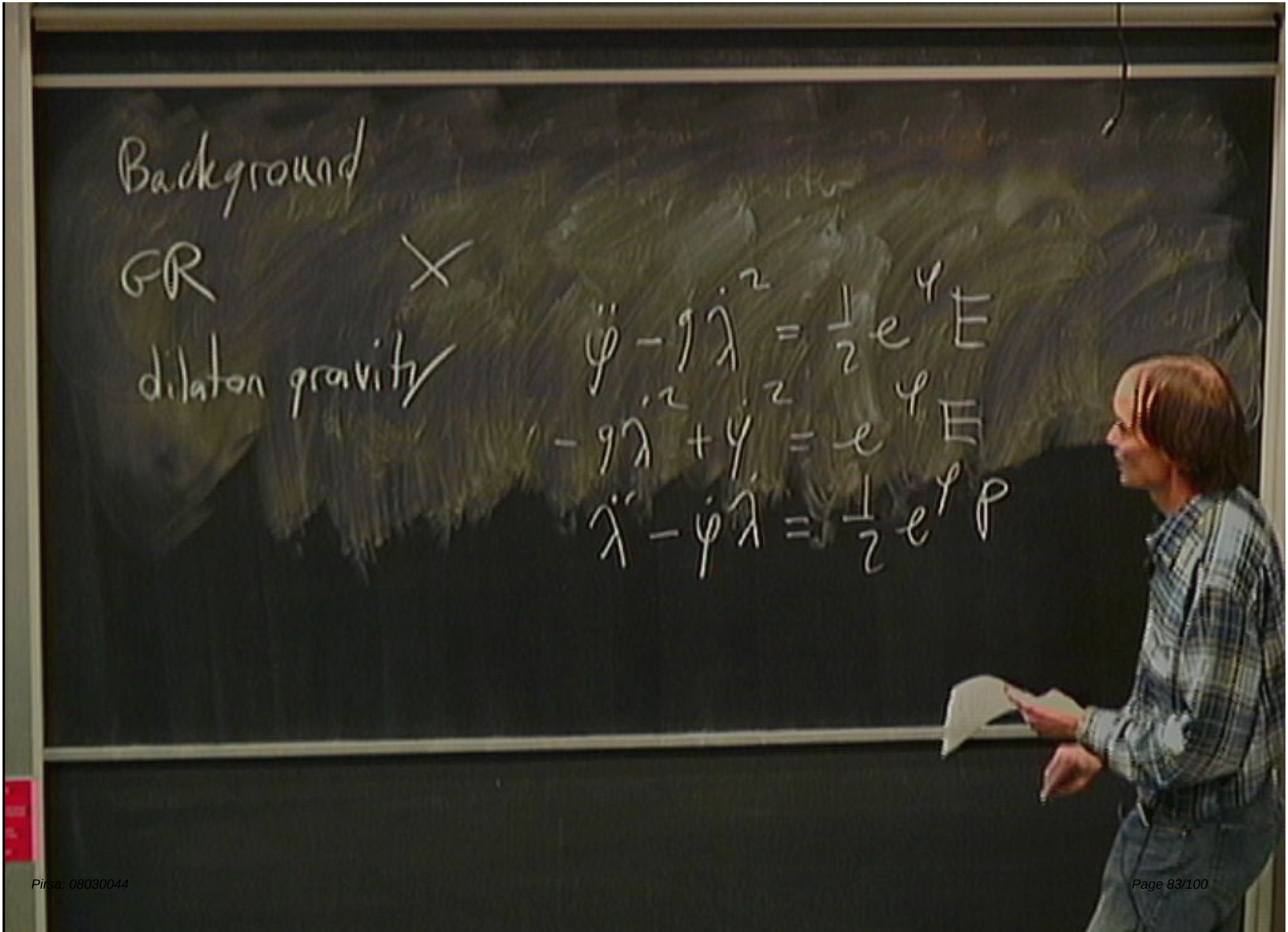
N. Lashkari


Background
GR

Background

GR

dilaton gravity


Background
GR ×
dilaton gravity ✓
$\ddot{\varphi} - g\dot{\lambda}^2 = \frac{1}{2} e^{\varphi} E$
$-g\dot{\lambda}^2 + \dot{\varphi}^2 = e^{\varphi} E$
$\ddot{\lambda} - \dot{\varphi}\dot{\lambda} = \frac{1}{2} e^{\varphi} \rho$

Background $\qquad a = e^{\lambda}$

GR $\times$

dilaton gravity $\checkmark$

string frame

$$\ddot{\varphi} - 9\dot{\lambda}^2 = \frac{1}{2} e^{\varphi} E$$

$$-9\dot{\lambda}^2 + \dot{\varphi}^2 = e^{\varphi} E$$

$$\ddot{\lambda} - \dot{\varphi}\dot{\lambda} = \frac{1}{2} e^{\varphi} p$$

Background $\qquad a = e^{\lambda}$

GR $\times$

dilaton gravity ✓

string frame

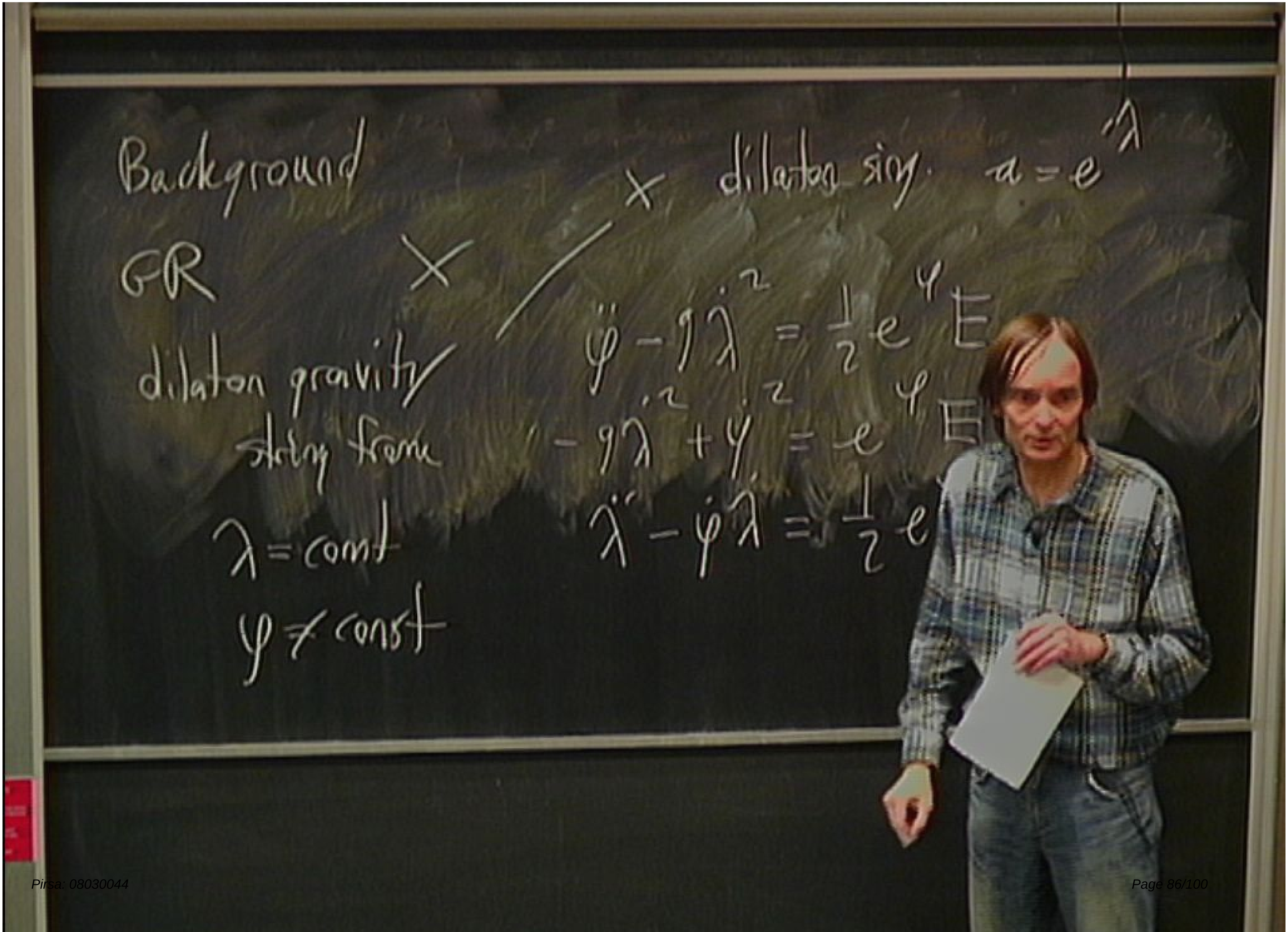
$\lambda = \text{const}$

$\varphi \neq \text{const}$

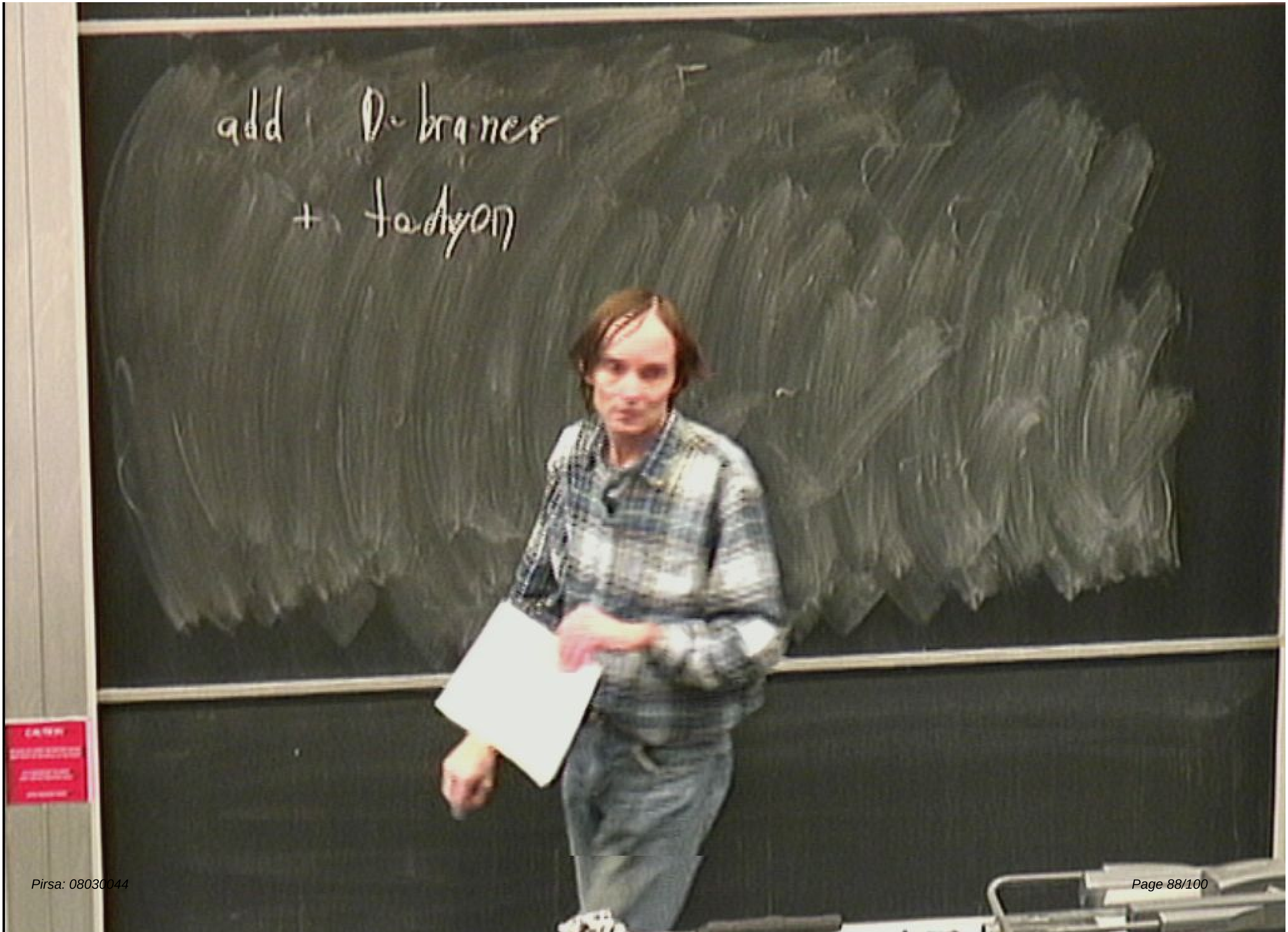
$$\ddot{\varphi} - 9\dot{\lambda}^2 = \frac{1}{2} e^{\varphi} E$$

$$-9\dot{\lambda}^2 + \dot{\varphi}^2 = e^{\varphi} E$$

$$\ddot{\lambda} - \dot{\varphi}\dot{\lambda} = \frac{1}{2} e^{\varphi} \rho$$


Background
GR
dilaton gravity
string frame
$\lambda = \text{const}$
$\varphi \neq \text{const}$
dilaton sing.
$a = e^{\lambda}$
$\ddot{\varphi} - 9\dot{\lambda}^2 = \frac{1}{2} e^{\varphi} E$
$-9\dot{\lambda}^2 + \dot{\varphi}^2 = e^{\varphi} E$
$\ddot{\lambda} - \dot{\varphi}\dot{\lambda} = \frac{1}{2} e$

add D-branes


add D-branes
+ tachyon

add : D-branes

+ tachyon

+ potential $V(\phi, \lambda)$

add D-branes

+ tachyon

+ potential $V(\phi,\lambda) = e^{-\gamma\lambda} W(\phi)$

add D-branes

+ tachyon $V(T)$

+ potential $V(\phi,\lambda) = e^{-\gamma\lambda} W(\phi)$

1. String Gas Cosmology (SGC)

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Progress

A. Nayeri, R.B. & C. Vafa 05

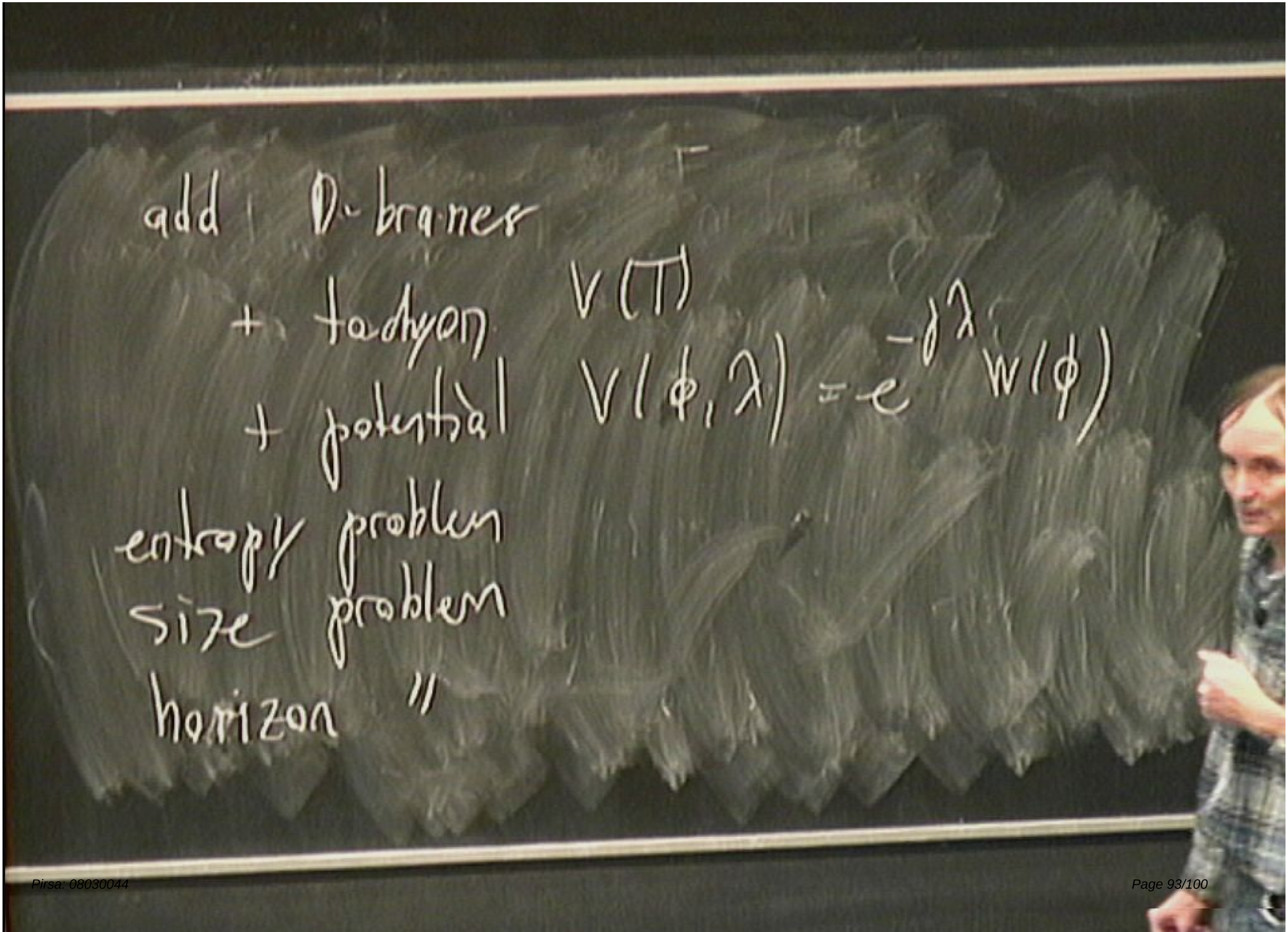
S. Patil & R.B. 05

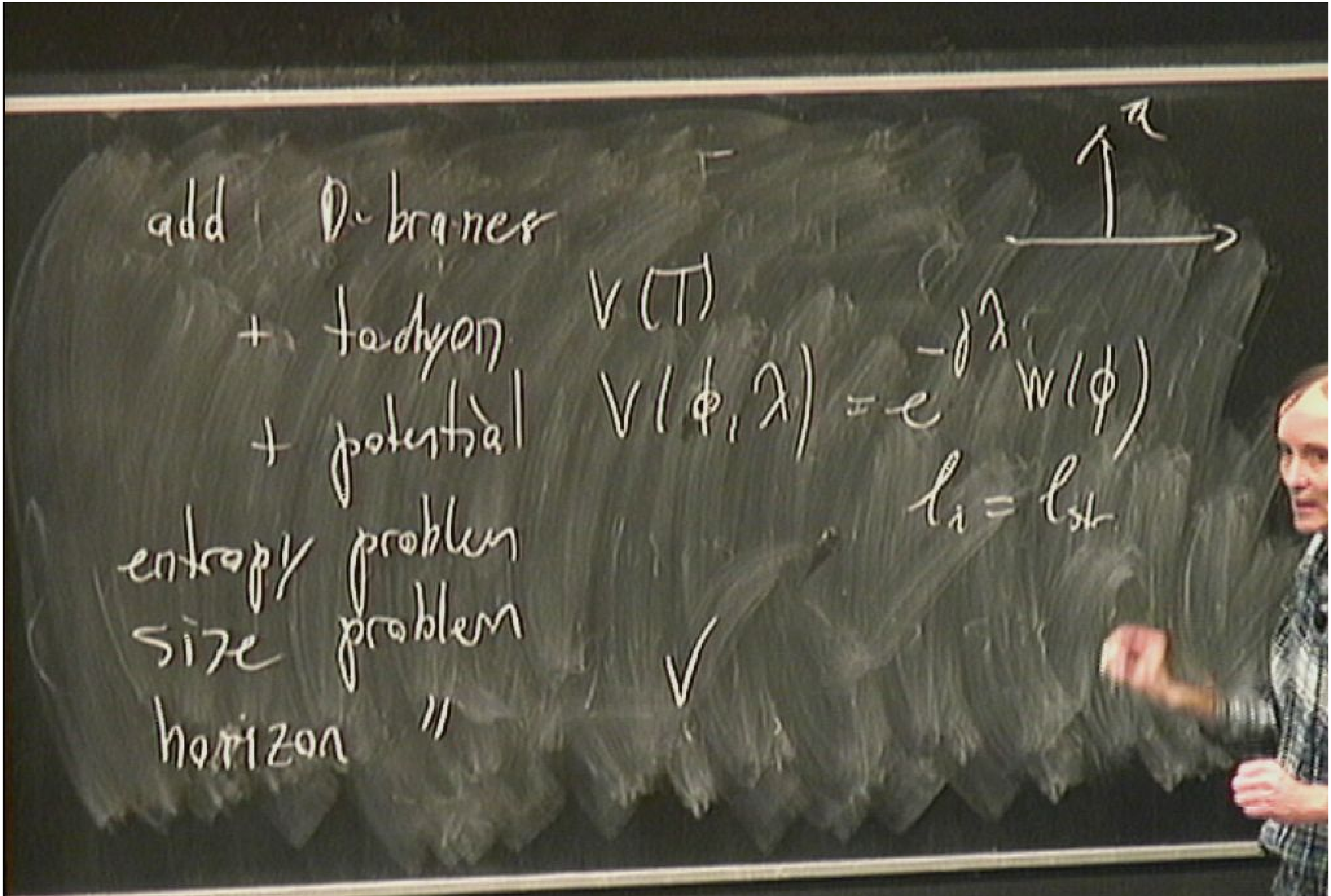
E. Cheung et. al 05

R. Danos, A. Frey & R.B 08

R.B, A. Frey & S. Kanno 07

N. Lashkari


add D-branes
+ tachyon $V(T)$
+ potential $V(\phi, \lambda) = e^{-\gamma\lambda} W(\phi)$
entropy problem
size problem
horizon "


add D-branes
+ tachyon V(T)
+ potential V(φ, λ) = e^{-γλ} W(φ)
l_1 = l_st
entropy problem
size problem
horizon "

add D-branes

+ tachyon $V(T)$

+ potential $V(\phi, \lambda) = e^{-d\lambda} W(\phi)$

$l_\lambda = l_{st}$

entropy problem ✓

size problem ✓

horizon " ✓

Jeans instability problem

add D-branes

+ tachyon $V(T)$

+ potential $V(\phi, \lambda) = e^{-\gamma\lambda} W(\phi)$

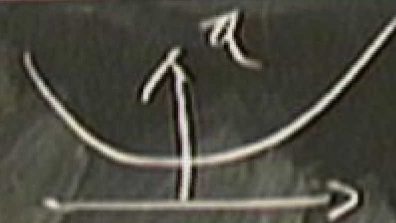
$l_1 = l_{st}$

entropy problem ✓

size problem ✓

horizon " ✓

Jeans instability problem



add D-branes

+ tachyon $V(T)$

+ potential $V(\phi, \lambda) = e^{-\gamma\lambda} W(\phi)$

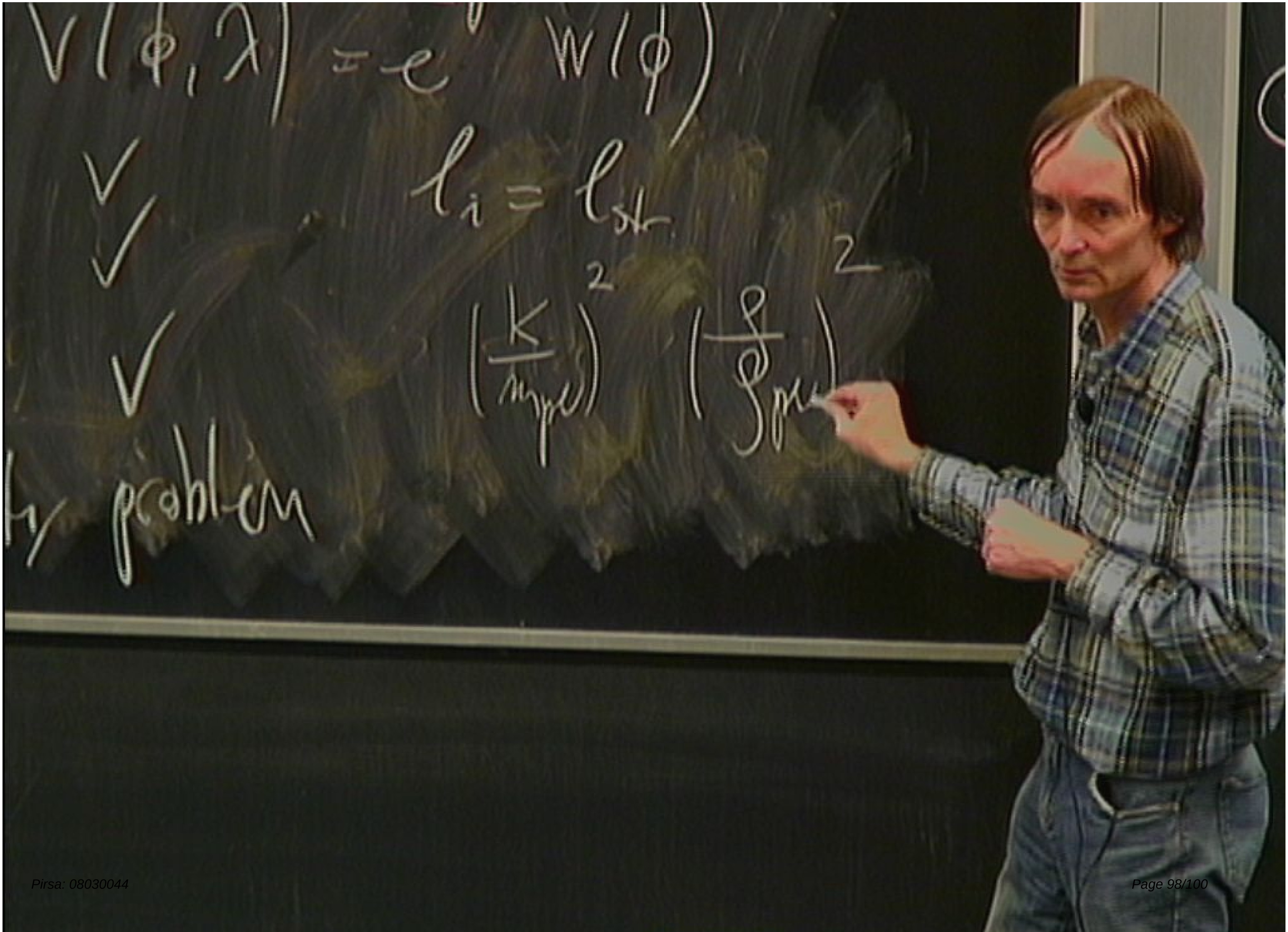
$l_\lambda = l_{st}$

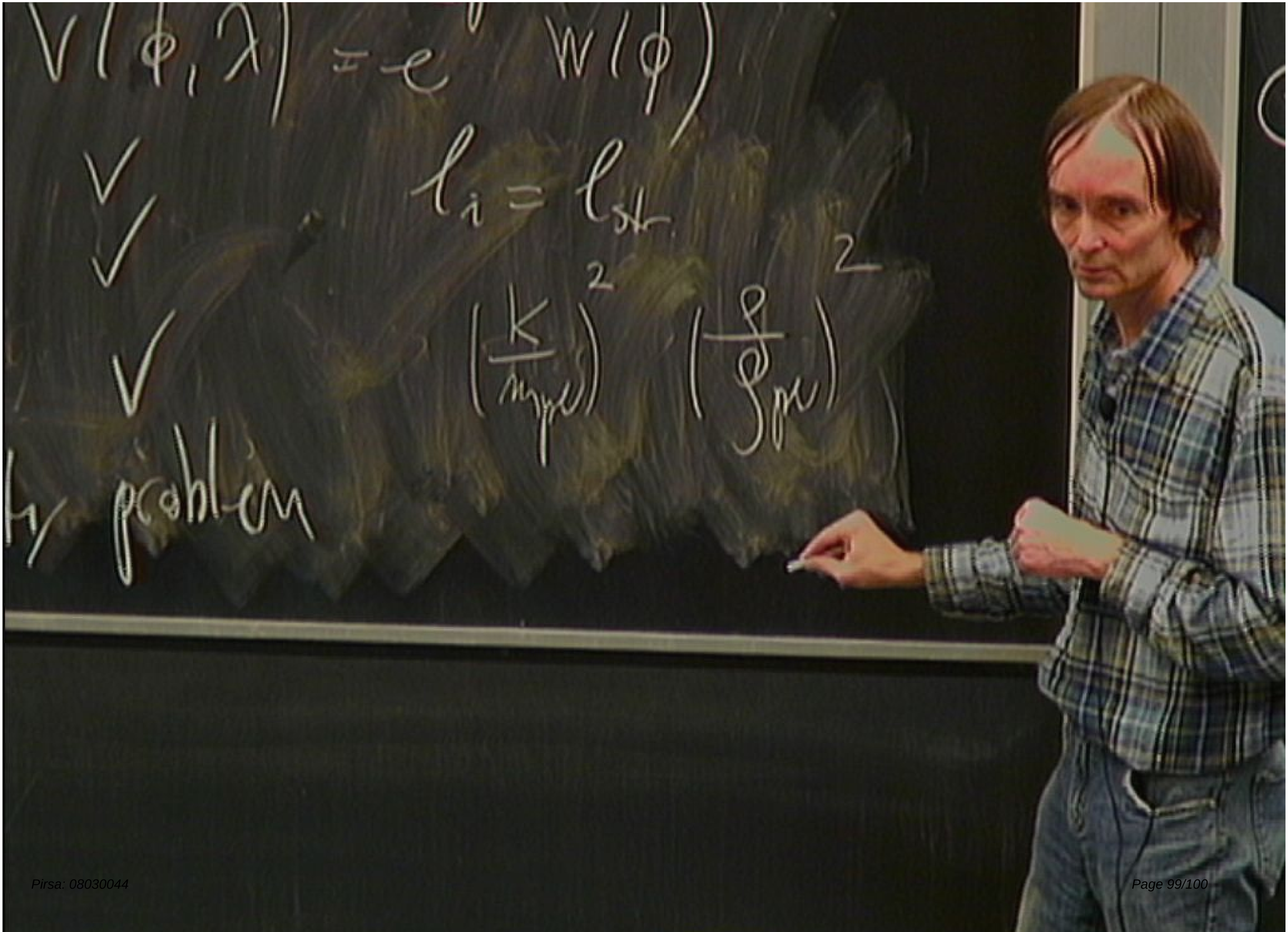
entropy problem ✓

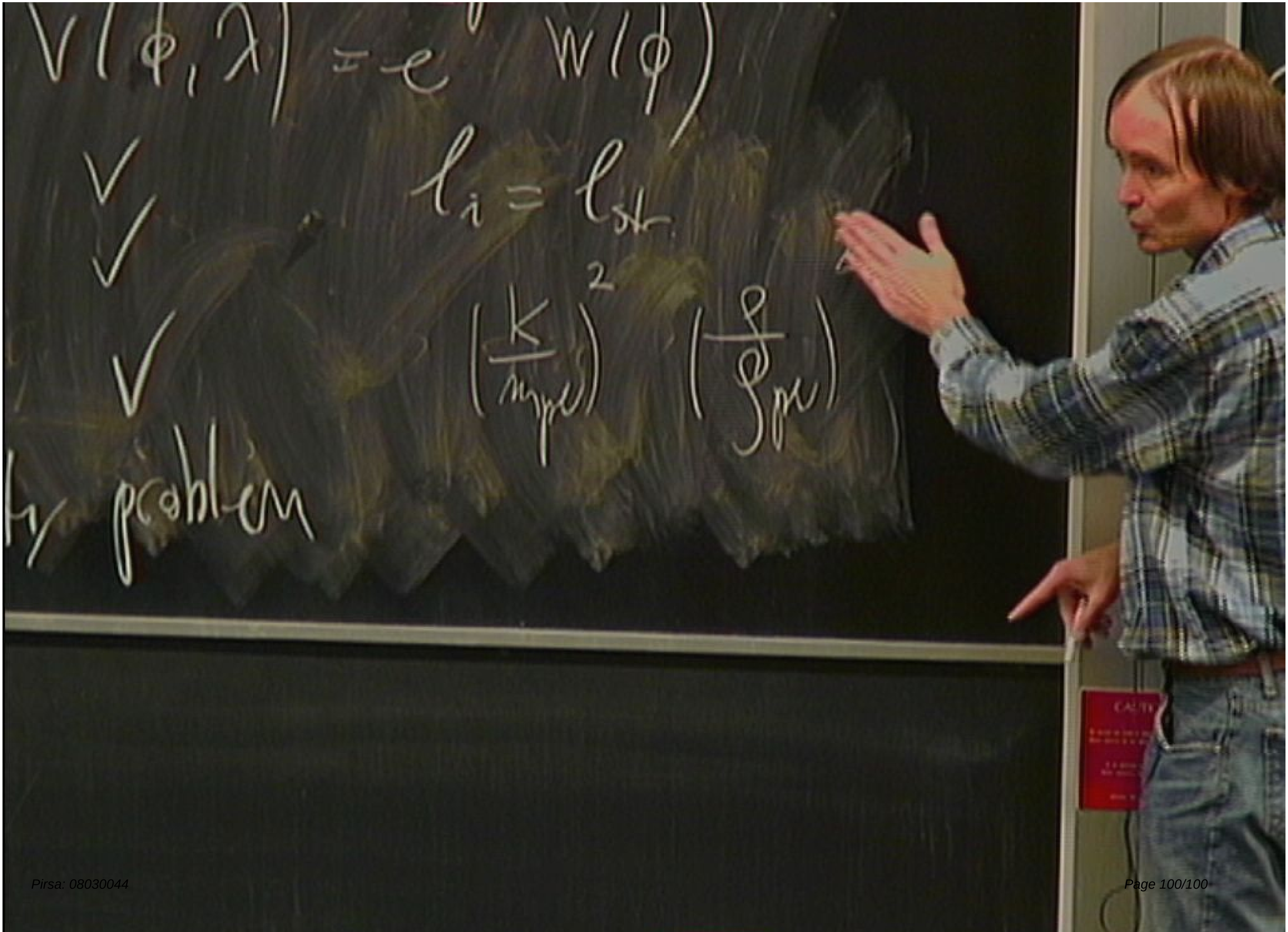
size problem ✓

horizon " ✓

Jeans instability problem


V(φ, λ) = e W(φ)
l_i = l_st
problem


$l_i = l_{st}$
problem


V(φ, λ) = e W(φ)
l_i = l_st
problem